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Proceedings - Institution of Mechanical Engineers

Institution of Mechanical Engineers (Great Britain),
Institution of Mechanical Engineers (Great Britain). Journal

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THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1899.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,

STOREY'S GATE, ST. JAMES'S PARK, WESTMINSTER, S.W.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86. (*Deceased* 1899.)

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889. (*Deceased* 1898.)

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

E. Windsor Richards, 1896–97.

Samuel Waite Johnson, 1898.

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The Institution of Mechanical Engineers.

OFFICERS.

1899.

PRESIDENT.

Sir William H. White, K.C.B., LL.D., D Sc., F.R.S., .. London.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., London.
Sir Edward H. Carbutt, Bart., ... London.
Jeremiah Head (*deceased March*, 1899), ... London.
Samuel Waite Johnson, ... Derby.
Alexander B. W. Kennedy, LL.D., F.R.S., ... London.
E. Windsor Richards, ... Caerleon.
John Robinson, ... Leek.
Percy G. B. Westmacott, ... Ascot.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., F.R.S., (*deceased March*, 1899) London.
Arthur Keen, ... Birmingham.
Edward P. Martin, ... Dowlais.
William H. Maw, ... London.
T. Hurry Riches, ... Cardiff.
A. Tannett Walker, ... Leeds.
J. Hartley Wicksteed, ... Leeds.

MEMBERS OF COUNCIL.

Sir William Arrol, M.P., LL.D., ... Glasgow.
John A. F. Aspinall, ... Horwich.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S., ... London.
Henry Chapman, ... London.
Henry Davey, ... London.
William Dean, ... Swindon.
Bryan Donkin, ... London.
Edward B. Ellington, ... London.
H. Graham Harris, ... London.
Henry Lea, ... Birmingham.
John G. Mair-Rumley, ... London.
Henry D. Marshall, ... Gainsborough.
The Right Hon. William J. Pirrie, ... Belfast.
Sir Thomas Richardson, M.P., ... Hartlepool.
John I. Thornycroft, F.R.S., ... London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Edgar Worthington,

The Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, S.W.

Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.

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THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

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4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

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year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

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Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

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3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

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EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

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specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

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19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

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COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

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27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

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(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

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35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

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By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

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6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s.*, but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s.* additional subscription for the current year, and £1 additional entrance fee.

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12. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

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arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

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23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

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27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

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31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

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36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

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APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

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FORM E.

I, the undersigned, being elected a of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of The Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of The Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

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The Institution of Mechanical Engineers.

PROCEEDINGS.

February 1899.

The Fifty-second Annual General Meeting of the Institution was held in the new House of the Institution, St. James's Park, London, on Thursday, 9th February 1899, at Half-past Seven o'clock p.m.; Samuel W. Johnson, Esq., Retiring President, in the chair, succeeded by Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President elected at the Meeting.

The President congratulated the Members of the Institution on being this evening for the first time assembled in the lecture hall of their own House. The building occupied a most unique and a most commanding position; it was substantially and elegantly built, and was one of which they could all feel justly proud. Fifty-two years ago, on 27th January 1847, the first meeting of the Institution took place at the Queen's Hotel, Birmingham, with George Stephenson as first President in the chair. There were at that time three Vice-Presidents, Joseph Miller of London, Charles F. Beyer of Manchester, and James Edward McConnell of Wolverton. There were also five Members of Council, all well known in the engineering world, namely Edward Humphrys of London, Benjamin Fothergill of Manchester, Joseph Radford of Manchester, William Buckle of Soho, and Edward A. Cowper of Smethwick. The number of the original members who joined in constituting the Institution at that date was fifty-six. Today the number of members of all classes on the roll of the Institution amounted to 2,684. Since 1847, up to last year 1898, there had

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(The President.)

been twenty-three Presidents, among whom were many of the most distinguished and most eminent engineers of the last half-century, whose names were prominently and indelibly interwoven with the national and engineering history of this period. All these Presidents had been concisely referred to, and their achievements recapitulated, by Mr. Windsor Richards in his presidential address at the Jubilee Meeting in Birmingham in July 1897. The Institution had been so successful hitherto, that he thought it was quite fair to anticipate it would meet with still greater success in the future; considering indeed the advantages which would be afforded by the Institution Building in the way of increased facilities and convenience for the members, it was more than probable that it would continue to be a material factor in forwarding the engineering prosperity, not only of Great Britain and her Colonies, but of the whole world. The date and arrangements had not yet been definitely settled for the new building to be formally opened; but probably the inauguration would take place some time in May, under the auspices of Sir William H. White as President. The opening ceremony, which he was sure the members would all agree with him could not possibly have fallen into better hands than Sir William's, would be duly announced at the proper time.

On behalf of the Council he had to express the deep regret which was felt at the loss by death, since the last meeting in October, of Sir William Anderson, K.C.B., whose high position and eminent attainments were well known to all; he had been the President of the Institution in the years 1892 and 1893. Also they had to regret the death of Sir John Fowler, Bart., K.C.M.G., and Mr. Robert Sinclair, the latter having been an eminent locomotive engineer; both had joined the Institution in 1847, the year of its commencement. And even so recently as two days ago they had to deplore the death of Mr. William Laird, who was so well known to all the members, and had been a Member of Council for the last twelve years.

The Minutes of the previous Meeting were read, approved, and signed by the President.

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The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following eighty-one candidates were found to be duly elected :—

MEMBERS.

BARLEY, CLEMENT JOHNSON,	London.
BOTTOMLEY, JOHN WILLIAM,	Leeds.
BOWLER, THOMAS,	Leeds.
BRUCE, GRAHAM STEWART,	Negapatam.
BUCHANAN, JAMES,	Liverpool.
COPPERTHWAITE, RALPH ATKINSON,	Middlesbrough.
COVENEY, WILLIAM CHARLES,	Singapore.
DANIA, GEORGE,	London.
DEWRANCE, JOHN,	London.
DITCHBURN, ROBERT,	Bombay.
GARDNER, WILLIAM,	London.
HATCH, WILLIAM THOMAS,	London.
HODGSON, HENRY,	Manchester.
HUMPHREY, HERBERT ALFRED,	Northwich.
HUTSON, CHARLES ALFRED,	Colombo.
JAMES, THOMAS,	Derby.
MARSLAND, JOHN SAMUEL,	Halifax.
MCLAREN, RICHARD ANDREW,	London.
MILLS, WILLIAM,	Manchester.
MUSGRAVE, JOHN RICHARD,	Leeds.
ORMSBY, ALFRED STEWART AUGUSTUS,	London.
PARRACK, WILLIAM THOMAS,	London.
THACKERAY, THOMAS,	London.
WARREN, FREDERICK FRIDLEZIUS,	Dublin.

ASSOCIATE MEMBERS.

BEGBIE, WILLIAM,	Johannesburg.
BEVEN, ALFRED NUGENT,	Junin, Chile.
BLISSETT, PERCIVAL THOMAS,	Bristol.
CARRACK, JOHN WILLIAM,	Nottingham.
CATER, JOHN MCILVAINE,	London.

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CLARK, GEORGE,	London.
CLERK, ARCHIBALD,	London.
COLLINS, WILLIAM LORENZO,	London.
DAY, CLAUD ALBERT STAINTON,	London.
DOUGLAS, WILLIAMS SAUNDERS,	Consett.
GALE, ROBERT HARRY,	Wisbech.
GOULSTONE, ERNEST EDWIN,	Cawnpore.
GREEN, JOHN SINGLETON,	Manchester.
HUGHES, FRANCIS EDWARD HAROLD,	London.
MARSHALL, LAUNCELOT PAUL,	Norwich.
MAW, HENRY,	London.
MCALL, HENRY WARDLAW,	Red Hill.
MCBEAN, JOHN,	Boksburg.
MCCORMACK, ARTHUR JOHN,	London.
MCTAGGART, JOHN,	Bradford.
MUIRHEAD, DAVID,	Nottingham.
MUNN, JOHN ADAM,	Calcutta.
PEARCE, STANDEN LEONARD,	London.
PIGOTT, ARTHUR,	London.
PILLING, FREDERICK STOTT,	Blackpool.
PROCKTER, FREDERICK MALCOLM,	Liverpool.
PUGH, JOHN VERNON,	Coventry.
QUILTER, FREDERIC RUSSELL,	London.
RADLEY, BERTRAM VERNON,	Asansol, India.
ROCHAT, HENRI LOUIS,	Calcutta.
ROWE, JOHN,	Johannesburg.
SECCHI, LEOPOLD,	London.
SHEFFIELD, FREDERICK GERARD,	Norwich.
SLINGSBY, WALTER,	Halifax.
SMITH, FRANCIS SUMNER,	London.
SPEIGHT, JAMES WILLIAM,	Blackpool.
SPILLER, CLAUDE,	Woolwich.
TAVERNER, HERBERT LACY,	Newcastle-on-Tyne.
TENNANT, WILLIAM JOHN,	London.
THOMAS, HUBERT ROBERT,	Wednesbury.
THOMAS, OWEN POWELL,	Colombo.

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THORNYCROFT, JOHN EDWARD, . . London.
WEST, HAARLEM ETHNEEN, . . London.
WHITEHOUSE, ALFRED, . . . Birmingham.

ASSOCIATES.

SACHS, EDWIN OTHO, . . . London.
SMITH, GEORGE ROBERT, . . . Leeds.
WILSON, JAMES MICHAEL GRAHAM, . London.

GRADUATES.

BRADLEY, CECIL GUSTAV, . . . Wolverhampton.
BROOKS, HARRY GORDON, . . . London.
DIMES, CHARLES WILLIAM, . . London.
GANDON, PHILIP GEORGE, . . . London.
GOOD, BASIL PRICE, . . . London.
LOWSLEY, SYDNEY EVAN, . . . Wolverhampton.
PARSONAGE, WILLIAM RAWLETT, . . Birmingham.
PASHBY, ARTHUR HAROLD, . . London.
SMITH, RAYMOND BERKELEY, . . London.
WARREN, ROBERT AUGUSTUS, . . Manchester.

The following six Transferences to the class of Members had been made by the Council since the last General Meeting:—

DICKINSON, HAROLD (*Associate Member*), . . Leeds.
HARRISON, FRANK (*Associate Member*), . . Calcutta.
HOUSE, HENRY A., JUN. (*Associate Member*), . Cowes.
MANTON, ARTHUR WOODROFFE (*Associate Member*), London.
MARSHALL, LEWIS (*Associate*), ... Halifax.
NAYLOR, SAM (*Associate*), ... Halifax.

The following Annual Report of the Council was then read:—

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ANNUAL REPORT OF THE COUNCIL.

1899.

The Council have the pleasure of presenting to the Fifty-second Annual General Meeting of the Members the following Report of the progress and work of the Institution during the past year.

At the end of last year the number of names in all classes on the roll of the Institution was 2,684, as compared with 2,493 at the end of the previous year, showing a net gain of 191. During 1898 there were added to the register 279 names; against which the loss by decease was 32, and by resignation or removal 56. These figures represent a slight decrease in losses, and also show that 55 more new members were added to the Institution than during the previous year, and 96 more than in the year 1896.

During 1898 Her Majesty has conferred upon Mr. T. Edward Vickers a Companionship of the Order of the Bath, and upon Mr. James Dredge a Companionship of the Order of St. Michael and St. George.

The following forty-seven Deceases of Members of the Institution have occurred during the past year:—

ALLEY, STEPHEN,	Glasgow.
ANDERSON, SIR WILLIAM, K.C.B., D.C.L., F.R.S.,	Woolwich.
BARRIE, WILLIAM,	Yokohama.
BECKWITH, JOHN HENRY,	Manchester.
BESSEMER, SIR HENRY, F.R.S.,	London.
BICKLE, THOMAS EDWIN,	Plymouth.
BICKNELL, EDWARD,	Bath.
BLACK, JAMES MARK,	Londonderry.
BORODIN, ALEXANDER,	St. Petersburg.
BRAND, DAVID JOLLIE (deceased 1897),	Queensland.
CLARK, CHRISTOPHER FISHER,	Wigan.

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COCHRANE, CHARLES,	Stourbridge.
DOBSON, SIR BENJAMIN ALFRED,	Bolton.
DOUGLASS, SIR JAMES NICHOLAS, F.R.S.,	Ventnor.
DRUMMOND, RICHARD OLIVER GARDNER,	Johannesburg.
EDEN, THE HON. FRANCIS FLEETWOOD,	Buenos Aires.
EDLIN, HERBERT WILLIAM (deceased 1897),	Johannesburg.
FOWLER, SIR JOHN, BART., K.C.M.G.,	London.
GAUNTLETT, WILLIAM HENRY,	Middlesbrough.
GJERS, JOHN,	Middlesbrough.
GLEDHILL, MANASSAH,	Manchester.
GOTTSCHALK, ALEXANDRE,	Paris.
HALL, GEORGE EDWARD,	Manchester.
HAYTER, HARRISON,	London.
HOPKINS, JOHN SATCHELL,	Birmingham.
HOPKINSON, JOHN, JUN., D.Sc., F.R.S.,	London.
HULSE, JOSEPH WHITWORTH,	Manchester.
MENZIES, WILLIAM,	Newcastle-on-Tyne.
MUDD, THOMAS,	West Hartlepool.
PEARCE, RICHARD,	Howrah, Bengal.
PHILIPSON, JOHN,	Newcastle-on-Tyne.
RAWLINS, JOHN,	Birmingham.
RICHARDS, LEWIS,	Bedlinog, Glam.
ROBERTSON, WILLIAM,	London.
SCHRAM, RICHARD,	London.
SHENTON, JAMES,	Manchester.
SINCLAIR, ROBERT,	London.
SPENCE, JOHN C. (Associate Member),	Johannesburg.
STOKER, FREDERICK WILLIAM,	Johannesburg.
STRYPE, WILLIAM GEORGE,	Dublin.
SWALE, GERALD (Graduate),	Victoria, B.C.
THOMASSON, LUCAS (Associate Member),	Hatfield.
WESTWOOD, JOSEPH,	Barkway, Herts.
WHITTEM, THOMAS SIBLEY,	Coventry.
WILLIAMS, WILLIAM LAWRENCE,	London.
WILSON, JOSEPH WILLIAM,	London.
WILSON, ROBERT, F.R.S.E.,	London.

Of these Sir William Anderson, Director-General of Ordnance Factories, was a Vice-President for four years during his terms of 1879–1885 and 1887–1891 as Member of Council, after which he was elected President for two years, 1892–3; Sir Henry Bessemer was a Member of Council from 1871 to 1878; Mr. Cochrane served

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on the Council from 1864 until he became President in 1889, having been a Vice-President for thirteen years; Sir Benjamin A. Dobson was a Member of Council from 1885 until his death, with the exception of the years 1892 and 1893; Sir James N. Douglass entered the Council in the same year, and was a Vice-President from 1889 to 1894, when he retired from ill health; Dr. John Hopkinson was a Member of Council from 1889; and Mr. Mudd from 1896. Sir John Fowler and Mr. Robert Sinclair were elected Members of the Institution in October 1847.

The following twenty-one gentlemen have ceased to be Members of the Institution during the past year:—

BOYER, ROBERT SKEFFINGTON,	Cardiff.
COMMON, JOHN FREELAND FERGUS,	Cardiff.
ETCHES, HARRY,	Brantford, Canada.
EVANSON, FREDERIC MACDONNELL,	Manchester.
FAUVEL, CHARLES JAMES (Associate),	London.
HANSELL, ROBERT BLACKWELL,	Baltimore.
HEINRICH, HERBERT RODOLPH (Graduate),	Chertsey.
HOLT, ROBERT,	London.
HULLAH, ARTHUR,	Bombay.
HUMPHRIES, EDWARD THOMAS,	Pershore.
IVATTS, LIONEL EDWARD,	Behobie, France.
KANTHACK, RALPH,	London.
KNIGHT, BERTRAND THORNTON,	Bangkok.
MÜLLER, HENRY ADOLPHUS,	Calcutta.
NELSON, ARTHUR DAVID,	Sydney.
PAULSON, SCOTT,	Cape Town.
RAFAREL, WILLIAM CLAUDE,	Barnstaple.
REDIT, DAVID,	Downham Market.
SMITH, WILLIAM,	Sydney.
STEWARD, GEORGE RICHARD,	London.
THOMSON, ROBERT MCNIDER,	Kobe, Japan.

In addition to these, thirty-five Resignations of membership took effect on 1st January 1898.

The Accounts for the year ending 31 December 1898 are now submitted to the Members (see pages 14–18) after having been

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passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £8,452 4*s.* 0*d.*, including the amount of £167 6*s.* 3*d.* over-reserved in the previous year, while the expenditure was £7,588 12*s.* 11*d.*, leaving a balance of receipts over expenditure of £863 11*s.* 1*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £66,462 18*s.* 4*d.*; and deducting therefrom the £25,000 of debentures, and allowing £432 13*s.* 9*d.* for accounts owing but not yet rendered (irrespective of the work in progress for the House), and £81 4*s.* 1*d.* unclaimed Debenture Interest, the capital of the Institution amounts to £40,949 0*s.* 6*d.* Of this sum £5,000 has been set aside as a sinking fund for the redemption of the debentures, leaving a balance of £35,949 0*s.* 6*d.* The sum of £15,403 4*s.* 4*d.* still remains invested in Railway Debenture and India Stocks and Consols, registered in the name of the Institution, while £47,544 8*s.* 6*d.* has already been expended on account of the Institution House. It will be seen from the balance sheet that, for the first time for many years past, the actual cost of the Investments, instead of their market value, is given in the assets, thus reducing the balance by nearly £3,000. The certificates of the securities have been duly audited by the Finance Committee and the auditor.

The progress of the Institution House at Storey's Gate, St. James's Park, has occupied the close attention of the Council during the year; and, although several delays have been caused by the completion of necessary agreements with the County Council and other bodies, your Council congratulate the Members on being able at last to enter with the new year into the occupation of our own commodious premises.

Experiments for the Research Committee on the Value of the Steam-Jacket have been carried on at University College, London, by Professor Beare. These have been recorded, and the Committee, under the chairmanship of Mr. Henry Davey, have decided on a

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further modification of the experimental apparatus and additional experiments before presenting their next Report.

Sir William C. Roberts-Austen has carried to a successful conclusion a long series of experiments which he has been making for the Institution in his laboratory at the Royal Mint on the behaviour of Steels during cooling; and his Fifth Report, dealing with the structure and properties of various steels containing different percentages of carbon, has been presented to the Alloys Research Committee, and adopted by them for reading and discussion at the present Meeting. The Committee at their recent Meeting elected Sir William H. White as their chairman, in the place of the late Sir William Anderson.

Professor F. W. Burstall's First Report to the Gas-Engine Research Committee, consisting of a description of apparatus and methods and preliminary results, was read and discussed at the Spring Meeting, and called forth useful comment from the Members who took part in the discussion. The Committee, under the chairmanship of Professor Kennedy, are continuing their investigations with the experimental gas-engine at Mason University College, Birmingham.

The compound steam-engine has now been fixed at King's College, London, for the Steam-Engine Research Committee. The chairman, Mr. Bryan Donkin, and the reporter, Professor Capper, hope to commence a series of experiments early this year.

For the additions to the Library of the Institution which have been received by presentation and exchange during the past year, as enumerated in pages 20–27, the Council here record their thanks to the several Donors. As the restricted library accommodation hitherto available in the old offices of the Institution is now succeeded by the ampler space provided in the new building, the Council look upon this enlargement as presenting a peculiarly favourable opportunity for welcoming from Members who have published works

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valuable for reference, or original pamphlets on engineering subjects, or records of experiments, copies of such publications for permanent preservation, and for enhancing the value of the Library.

The General Meetings in 1898 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Derby; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of ten of the following Papers, which are published in the Proceedings:—

Mechanical features of Electric Traction; by Mr. Philip Dawson.

Diagrams to facilitate the design of Riveted Joints for Boiler Work; by Professor W. E. Dalby.

Address by the President, Samuel W. Johnson, Esq.

First Report to the Gas-Engine Research Committee: description of apparatus and methods, and preliminary results; by Professor Frederic W. Burstall.

Steam Laundry Machinery; by Mr. Sidney Tebbutt.

Aluminium Manufacture, with description of the Rolling Mills and Foundry at Milton, Staffordshire; by Mr. E. Ristori.

Narrow-Gauge Railways, of two feet gauge and under; by Mr. Leslie S. Robertson.

Water Softening and Purification by the Archbutt-Deeley Process; by Mr. Leonard Archbutt.

Electric Installations for Lighting and Power on the Midland Railway, with notes on Power absorbed by Shafting and Belting; by Mr. W. E. Langdon.

Results of recent practical experience with Express Locomotive Engines; by Mr. Walter M. Smith.

Mechanical Testing of Materials at the Locomotive Works of the Midland Railway, Derby; by Mr. W. Gadsby Peet.

The attendances during 1898 were as follows:—at the Annual General Meeting 136 Members and 113 Visitors; at the Spring Meeting 130 Members and 57 Visitors; at the Summer Meeting 512 Members and 81 Visitors; and at the Autumn Meeting 132 Members and 80 Visitors. These figures show an improvement in the attendance of members amounting to 54 per cent., 106 per cent., 26 per cent., and 48 per cent. respectively at the four meetings of the Institution, the largest increase being at the reading and discussion of Papers in London.

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The President's Address, dealing with the History of the Midland Railway and its Rolling Stock, was delivered at the Spring Meeting, and has attracted considerable attention throughout the railway world.

The Summer Meeting was held in Derby, the headquarters of all the engineering departments of the Midland Railway, of which the Chairman and Directors granted substantial facilities to individual Members attending the Meeting. In the three Papers read important subjects of special local interest were dealt with, and were well discussed. Subsequently the Members were able to add to their interest in each of these subjects by visiting the British Aluminium Works at Milton, the water-softening apparatus of the Midland Railway and several small villages, and the Duffield Bank narrow-gauge railway, in addition to a large number of works in Derby and Nottingham and the neighbourhood. Excursions were made to Stoke, Burton, Loughborough, Swithland, Nottingham, and the Dukeries. The Members were also hospitably entertained by the President at a garden party in the grounds of Nottingham Castle; and by the Local Committee, under the chairmanship of Sir A. Seale Haslam, at a conversazione in the Derby Art Gallery. The work of arranging the details of the programme was ably carried out by Mr. R. Mountford Deeley and Mr. George J. Pratt of Derby as joint Honorary Secretaries; and the Council have marked their appreciation of their active exertions by presenting to each on behalf of the Members a silver salver, bearing an inscription recording their grateful acknowledgment of the services rendered.

The Council purpose holding the Summer Meeting of the Institution this year in Plymouth.

Several Members of the Council have given evidence before the National Physical Laboratory Committee; others have represented the Institution at the Autumn Congress of the Sanitary Institute in Birmingham, and at the Jubilee Meeting of the French Society of [illegible] Engineers in Paris. The Council are in consultation with the

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Association of Technical Institutions for the purpose of encouraging their most promising students to affiliate themselves with this Institution.

At this Meeting the Members have to elect a President, three Vice-Presidents, and seven Members of Council, to fill the vacancies caused by retirement and by death. The result of the ballot for these elections will be announced to the Meeting. The Council regret to inform the Members that the President is unable to accept office for the ensuing year, owing to other important duties making too great demands upon his time; they have therefore nominated Sir William H. White for the presidency, and he has accepted the nomination.

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Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£ s. d.	£ s. d.
To Editing, Printing, and Engraving Proceedings	2,040 17 10	
„ Reprinting former Proceedings	21 4 0	
	2,062 1 10	
Less Authors' Copies of Papers, repaid	5 11 6	2,056 10 4
„ Stationery and General Printing		257 6 1
„ Binding		28 14 4
„ Rent of Offices (19 Victoria Street)		710 0 0
„ Salaries and Wages		2,063 17 6
„ Coal, Firewood, and Lighting		50 7 1
„ Fittings and Repairs		27 6 11
„ Postages, Telegrams, and Telephone		328 12 1
„ Insurance		42 7 9
„ Travelling Expenses		3 13 4
„ Petty Expenses		51 16 9
„ Meeting Expenses—		
Printing	286 17 9	
Reporting	51 14 0	
Diagrams, Screen, &c.	111 14 1	
Travelling and Incidental Expenses	172 5 10	622 11 8
„ Dinner Guests		56 4 10
„ Research		217 8 10
„ Books purchased		27 7 4
„ Removal (part)		44 8 0
„ Debenture Interest		1,000 0 1
		7,588 12 11
Balance, being excess of Receipts over Expenditure, carried down—		863 11 1
		£8,452 4 0

To Honorarium to retiring Secretary		3,000 0 0
To House for Institution—		
Expended on Building this year	16,257 19 7	
Ground Rent during construction	850 8 2	17,108 7 9
Cash Balance 31st December 1898	1,495 1 5	
Add amount over-reserved as above	167 6 3	1,662 7 8
		£21,770 15 5

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FOR THE YEAR ENDING 31ST DECEMBER 1898. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
124 *New Members at £2*	248	0	0			
103 *New Associate Members at £1*	103	0	0			
13 *New Associates at £1*	13	0	0			
14 *Associate Members transferred to Members at £1*	14	0	0			
2 *Associates transferred to Members at £1*	2	0	0			
1 *Graduate transferred to Member at £1*	1	0	0	381	0	0
„ Subscriptions for 1898—						
1747 *Members at £3*	5,241	0	0			
361 *Associate Members at £2 10s.*	902	10	0			
81 *Associates at £2 10s.*	202	10	0			
184 *Graduates at £1 10s.*	276	0	0			
14 *Associate Members transferred to Members at 10s.*	7	0	0			
2 *Associates transferred to Members at 10s.*	1	0	0			
1 *Graduate transferred to Member at £1 10s.*	1	10	0			
4 *Graduates transferred to Associate Members at £1*	4	0	0	6,635	10	0
„ Subscriptions in arrear—						
70 *Members at £3*	210	0	0			
12 *Associate Members at £2 10s.*	30	0	0			
2 *Associates at £2 10s.*	5	0	0			
2 *Graduates at £2*	4	0	0			
16 *Graduates at £1 10s.*	24	0	0	273	0	0
„ Subscriptions in advance—						
25 *Members at £3*	75	0	0			
1 *Associate Member at £2 10s.*	2	10	0			
2 *Associates at £2 10s.*	5	0	0			
3 *Graduates at £1 10s.*	4	10	0			
	87	0	0			
Less 1 *Graduate at £1 10s., refunded*	1	10	0	85	10	0
„ Interest—						
From Investments	743	7	0			
From Bank	17	10	7			
Income Tax refunded (3 *years*)	75	15	6	836	13	1
„ Reports of Proceedings—						
Extra Copies sold				73	4	8
„ Reserve in previous year against accounts owing	600	0	0			
Less general accounts owing, not yet rendered	432	13	9	167	6	3
				£8,452	4	0
By Balance brought down				863	11	1
By Life Compositions				212	0	0
By Sale of Investments				16,642	13	0
Cash Balance 31st December 1897				4,052	11	4
				£21,770	15	5

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Dr. **BALANCE SHEET**

	£	s.	d.	£	s.	d.
To Debentures—						
250 *of* £100 *each at* 4%, *redeemable in* 1917, *or at par at any date after* 1st *Jan.* 1908, *on six months' notice to holder*				25,000	0	0
„ Sundry Creditors—						
Accounts owing, not yet rendered, say	432	13	9			
Unclaimed Debenture Interest	81	4	1			
				513	17	10
Capital of the Institution :—						
(1) *Excess of Assets over Liabilities at this date*	35,949	0	6			
(2) *Set aside during* 1897–98 *as a Sinking Fund for redemption of Debentures* .	5,000	0	0			
				40,949	0	6*
(exclusive of back numbers of Proceedings, which cost £5,200)						

* Note.—*The diminution in this Balance as compared with last year is chiefly in consequence of the Finance Committee having decided that now and for the future the Cost of the Investments, instead of their Market Value, shall rank in the Assets.*

£66,462 18 4

Signed by the following members of the Finance Committee:—

E. WINDSOR RICHARDS, WILLIAM H. MAW,
DOUGLAS GALTON, BRYAN DONKIN,
ARTHUR KEEN, JOHN G. MAIR-RUMLEY.

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AS AT 31ST DECEMBER 1898. *Cr.*

							£	s.	d.
By House for Institution, expenditure to date							47,544	8	6
„ Investments							*cost* 15,403	4	4
£									
4,237	*London and North Western Ry.*	3%	*Debenture Stock*						
3,945 12*s.*	*Midland Railway*	2½%	„	„					
4,053	*India* 3% *Stock*								
5,000	*Consols* 2¾%								
The Market Value of these investments at 31*st Dec.* 1898 *was about* £18,281, *of which* £5,000 *is reserved for the Sinking Fund.*									
					£	s.	d.		
„ Cash—*In Union Bank, on Current account* . .					995	1	5		
In London Joint Stock Bank				342	11	7			
Cash balance at 3rd Dec. 1898 (*when expenditure account closed*) *since spent*				157	8	5	500	0	0	1,495	1	5
In Union Bank, unclaimed Debenture Interest . . .										81	4	1
„ Library										1,240	0	0
„ Subscriptions in Arrear, probable value										256	0	0
„ Office Furniture and Fittings										343	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .										100	0	0
„ Proceedings, back numbers, cost £5,200												
										£66,462	18	4

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

D

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WILLANS PREMIUM FUND.

Investment £159 8s. 5d. of India 3% Stock . . . . cost £165 5s. 0d.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Institution of Electrical Engineers . . .	11	18	4	By Interest, 1895-96-97	11	18	4
„ Balance, held in trust .	4	15	4	„ „ 1898 . .	4	15	4
	£16	13	8		£16	13	8

Audited, certified, and signed by the names on pages 16–17.

The next award of the Premium at the end of the year 1900 devolves upon the Council of this Institution.

DECLARATION OF TRUST OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and

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when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by The Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof The Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of The Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

The Seal of The Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary; and the document was signed as follows:—

ALEXANDER B. W. KENNEDY,
President of The Institution of Mechanical Engineers.

R. E. CROMPTON,
President of The Institution of Electrical Engineers.

F. H. Webb, Secretary of The Institution of Electrical Engineers.

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LIST OF DONATIONS TO THE LIBRARY.

Message from the President of the U.S. America, transmitting Report upon the destruction of the "Maine"; from the U.S. President.

The Heat Efficiency of Steam Boilers: Land, Marine, and Locomotive, by Bryan Donkin; from the author.

Elements of Machine Construction and Drawing, by H. J. Spooner and E. G. Davey; from the publishers.

Engineering Arithmetic and Mensuration, by C. R. Honiball; from the author.

Cours d'Électricité, théorie et pratique, by C. Sarasin; from the publishers.

Contribution to the History of the Respiration of Man, by William Marcet, M.D., F.R.C.P., F.R.S.; from Mr. James P. Maginnis.

Essays on Social Topics, by Lady Cook; from the authoress.

Manchester Corporation Electricity Department: Rules as to the Supply of Electric Energy; from Mr. C. H. Wordingham.

Reminiscences of Russia in 1897, by J. Cartmell Ridley; from the author.

Light Railways, by Leslie S. Robinson; from the author.

Railway Technical Vocabulary, by L. Serraillier; from the author.

Paris Exhibition, 1900; from Mr. L. Serraillier.

Steam Tables and Engine Constants, by T. Pray, Jun.; Calorimeter Tables for Steam, by T. Pray, Jun.; from the author.

Theta-phi Diagram practically applied to Steam, Gas, Oil, and Air Engines, by H. A. Golding; from the author.

Moteurs à Gaz et à Pétrole, by A. Witz; from the publishers.

The Indicator Handbook, by C. N. Pickworth; from the author.

Aid Book to Engineering Enterprise, by Ewing Matheson; from the author.

Adulteration of Portland Cement, by W. H. Stanger and B. Blount; from the authors.

The Theory and Practice of Electrolytic Methods of Analysis, by Dr. B. Neumann, translated by J. B. C. Kershaw; Alternate Currents in Practice, by F. J. Moffett; from the publishers.

Queensland Past and Present, by T. Weedon; from Mr. John B. Henderson.

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1897; from Mr. John B. Henderson.

Empire of Austria, Patent Law dated 11 January 1897, translated by Paget Moeller and Hardy; from Mr. J. G. Hardy.

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Review of the Japanese Patent Law, by W. Silver Hall; from the author.

The following from the U.S. Geological Survey:—Seventeenth Annual Report, Parts I and II, 1895-96; Monographs, XXV-XXVIII (with Atlas) and XXX; Bulletins, 87-89, 127, 130, 135-149.

The following from the U.S. Ordnance Office:—Annual Report of the United States Chief of Ordnance, 1897; Tests of Metals, &c., at Watertown Arsenal, Massachusetts, 1896; Notes on the Construction of Ordnance.

Inaugural Address to the Manchester Association of Engineers by the President, Mr. Henry Webb, 15 January 1898; from the author.

Impermeabilización de Tejidos, by F. Aramburu; from the author.

General Rules recommended for Wiring for the Supply of Electrical Energy; from the Institution of Electrical Engineers.

Rede zum Geburts-feste seiner Majestät des Kaisers und Königs Wilhelm II in der Aula der Königlichen Technischen Hoch-schule zu Berlin, 26 Januar 1898; from the Rector.

Method of Measuring the Pressure at any point on a Structure, due to Wind blowing against that Structure, by Professor F. E. Nipher; from the author.

Tests of the Synchronograph on the Telegraph Lines of the British Government, by Drs. Crehore and Squier; from the authors.

Some Iron and Steel Works of the United States, by Franklin Hilton; from the author.

Torquay Waterworks, by William Ingham; from the author.

Matériel et Procédés de l'Exploitation des Mines à l'Exposition internationale de Bruxelles en 1897, by V. Watteyne and A. Halleux; from Mr. James Dredge, C.M.G.

West Indies and Sugar Bounties.

Tests for Steel Castings (large and small), Capstans and Gear, and Steel Castings for Machinery; Specification for Steel and Steel Wire for Ordnance; from Sir William H. White, K.C.B., LL.D., F.R.S.

List of Chinese Lighthouses, Light-Vessels, Buoys, and Beacons, 1898; from the Inspector General of Chinese Customs.

Construction of Inclined Gas-Retorts, Charging Apparatus, and Conveying Machinery, by M. Graham; from the author.

Clyde Navigation: Description of No. 3 Graving Dock, Glasgow, by J. Deas; from the author.

Notes on American Iron and Steel Practice, by A. P. Head; from the author.

Report of the Kew Observatory Committee, 1897; Notes on Thermometry, by C. Chree; from the Committee.

Marine Boilers, by L. E. Bertin, translated by Leslie S. Robertson; from the translator.

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Science and Engineering, 1837-97, by C. Bright; from the publishers.

Note sur l'Unification des Filetages, by F. G. Kreutzberger; from the author.

Suggested Rules for the Recovery of Coal Mines after Explosions, by W. E. Garforth; from the Federated Institution of Mining Engineers.

Ventilation of the Metropolitan Railway Tunnels; from Mr. Edgar Worthington.

Cold Hop Storage, by L. Sterne; from the author.

Proposed High-level Roadway Bridge across the River Mersey at Liverpool; from Mr. John James Webster.

British India's future Standard Currency, by J. H. Norman; from the author.

Ramsgate Corporation Water Department, New Pumping Station: account of Opening Ceremony; from Mr. W. A. M. Valon.

Festschrift zur XXXIX Haupt-versammlung des Vereines Deutscher Ingenieure, Chemnitz 1898; from the Chemnitz branch of the Verein Deutscher Ingenieure.

Balancing of Engines, by J. Whitcher; from the author.

Lubrication and Traction relating to Railway Carriages, by T. G. Clayton; from the author.

Report of the Inspection of Mines in India, 31 December 1896; from the India Office.

Classification Bibliographique Décimale, by E. Sauvage; from the author.

Minimum-Gauge Railways, their application, construction, and working, by Sir Arthur P. Heywood, Bart.; from the author.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1897 and 30 June 1898; from the Registrar.

Wire Rope and its Applications, by W. E. Hipkins; from the author.

Basic Refined Steel on the Continent, by C. E. Stromeyer; from the author.

Jersey New Waterworks, Bye-laws, Regulations, &c.; from Mr. Hugh G. Foster-Barham.

Evolution of the Locomotive Engine, by W. P. Marshall; from the author.

Instruments for Measuring small Torsional Strains, by E. G. Coker; from the author.

The following official publications from the Government of New South Wales:—Annual Report of the Railway Commissioners for the year ending 30 June 1898; Reports of the Department of Public Works for the years ending 30 June 1896 and 30 June 1897; Report relating to the proposed duplicate Main from Prospect to Potts' Hill; Report relating to the proposed New Bridge at Glebe Island; three Reports of Royal Commissions to enquire into management of—(1) Hunter District Water Supply and Sewerage Board, (2) Metropolitan Water Supply and Sewerage Board, (3) Working of Mines and Quarries in the Albert Mining District; Wealth and Progress of New South Wales, Vol. II, 1895-6 and 1896-7, by T. A. Coghlan.

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Journal of the Society of Mechanical Engineers, Japan, Vol. I, No. I, December 1897; from Professor Bunji Mano.

Local Government Board and the Protection of Water from Pollution, by P. Griffith; from the author.

Commercial Aspect of Engineering, by C. E. Larard; from the author.

Methods of dealing with Condensation, by J. Buley; from the author.

Wellington (N.Z.) Main Drainage, History of the Scheme; from Mr. W. Ferguson.

Liverpool and London and Globe Electrical Installation Rules, Special Risks' Supplement; from the company.

Report on the working of the Megass Lessivage system at Rodah; Perichon system of Megass Lixiviation at Rodah; from Messrs. Groig and Wilson.

Steel Permanent Way, by R. Price-Williams; from the author.

Report of a Visit to Technical Colleges &c. in the United States and Canada, 1898; from the Manchester Technical Instruction Committee.

State of Nicaragua, by G. Niederlein; Republic of Costa Rica; from the Philadelphia Museums.

Neuere Zahn-rad-bahnen, by E. Brückmann; from the author.

Replica di Krupp alla protesta del Signor Bashforth, translation by Rev. F. Bashforth; from the translator.

Report on the working of the Public Works Workshops, Madras, 1897–8; from Mr. H. Moss.

Manchester Electric Trams, Conduit System versus Overhead Trolley, by Hans Renold; from the author.

Under-Frame and Body for a four-wheeled Truck, by L. J. Bika; from the author.

Cinquantenaire de l'Association des Ingénieurs sortis de l'École de Liége; from the Association.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Yorkshire College, Leeds, Annual Report, 1896–97; from the College.

University of California, Annual Report of Secretary, 1896; Register, 1896–97; from the University.

City and Guilds of London Institute, Report to the Governors, March 1898; from the Institute.

University College, Sheffield, Calendar 1897–98; from the College.

University College of South Wales and Monmouthshire, Calendar 1897–98; from the College.

Calendars 1898–99 from the following Colleges:—Royal Technical High School, Berlin; Mason University College, Birmingham; Municipal Technical School, Birmingham; University College, Bristol; Cardiff Technical School (Prospectus); Glasgow and West of Scotland Technical College; Yorkshire College, Leeds; City of London College; King's College, London; McGill University, Montreal; Royal Technical High School,

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Munich (with Report); University College, Sheffield; Civil Engineering College, Sibpur.

Lockwood's Builder's and Contractor's Price-book, 1898; from the publishers.

Spons' Engineers' and Contractors' Diary and Year-book, 1898; from the publishers.

Engineers' Compendium, 1898; from the publishers.

Abridgments of Specifications of Patents for Inventions, 1889–92—Classes 1–8, 10–19, 21–54, 56–77, 79–81, 84–105, 107–124, 126–146; Catalogue of the Library of the Patent Office, Vol. I, Authors, 1898; from the Patent Office.

Illustrated Catalogue of Machinery and Tools; from Mr. George Hatch.

Illustrated Catalogue of Mathematical Instruments; from Mr. W. F. Stanley.

Illustrated Catalogue of Diving Apparatus; from Messrs. Siebe, Gorman and Co.

Royal Societies Club, List of Members, &c., 1897–8; from the Club.

Illustrated Catalogue of Printing Machines, &c.; from Messrs. Furnival and Co.

Illustrations of Electric Traction; from the British Thomson-Houston Co.

Universal Directory of Railway Officials, 1898; from the publishers.

Donaldson's Engineers' Annual and Almanac, 1899; from Mr. Philip R. Owens.

Baldwin Locomotive Works, Record of recent construction, 1898; from the company.

Water Supply to Villages and Country Houses; from Messrs. Merryweather and Sons.

Standards of Length and their practical application; from the Pratt and Whitney Co.

Fowler's "Mechanical Engineer" Pocket Book, 1899; from the publishers.

Pocket Hand-book of Electro-glazed Luxfer Prisms; from the Luxfer Prism Co.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Annales des Mines.

Annales du Conservatoire des Arts et Métiers.

Journal of the Marseilles Scientific and Industrial Society.

Proceedings of the Industrial Society of St. Quentin et de l'Aisne.

Proceedings of the Industrial Society of the North of France.

Proceedings of the Industrial Society of Rouen.

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Proceedings of the Industrial Society of Mulhouse.
Bulletins of the French Technical Maritime Association.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Bulletins of the International Railway Congress.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Technicky Obzor, Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Teknisk Ugeblad, Christiania.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions and Proceedings of the American Philosophical Society.
Journal of the Western Society of Engineers, Chicago.
School of Mines Quarterly, Columbia College, New York.
Reports of the Smithsonian Institution, Washington.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Transactions of the Australasian Institute of Mining Engineers.
Proceedings of the Engineering Association of New South Wales.
Journal and Proceedings of the Royal Society of New South Wales.
South African Association of Engineers and Architects, Proceedings, Vol. III, 1895-7.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the Civil and Mechanical Engineers' Society.

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Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the South Staffordshire Institute of Iron and Steel Works' Managers.
Philosophical Transactions and Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Report of the British Association for the Advancement of Science.
Transactions of the British Association of Waterworks Engineers.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Science Abstracts—Physics and Electrical Engineering.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Transactions of the Manchester Association of Engineers.
Transactions of the Institution of Junior Engineers.
Journal of the West of Scotland Iron and Steel Institute.
Annual Report of the Birmingham Association of Mechanical Engineers, 1897.

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Publications of the British Fire Prevention Committee.
Reports of the Manchester Steam Users' Association; from the Association.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Forty-fifth Annual Report of the Liverpool Free Public Library.
Forty-sixth Annual Report of the Manchester Public Free Libraries.
Fifteenth Annual Report of the Barrow-in-Furness Free Public Library.
Third Annual Report 1897 of the John Crerar Library, Chicago.
Catalogue of Additions during 1897 to the Radcliffe Library, Oxford.
Annual Report of the Library Syndicate, Cambridge, 1897.

The following Periodicals from the respective Editors:—

Arms and Explosives.
The Builder.
Camera Club Journal.
Cassier's Magazine.
The Colliery Guardian.
The Contract Journal.
Domestic Engineering.
The Electrical Engineer.
The Electrical Review.
The Electrician.
The Engineer.
The Engineer and Iron Trades' Advertiser.
Engineering.
The Engineering Magazine.
The Engineering Record.
The Engineering and Mining Journal.
Engineers' Gazette.
The Fireman.
The Journal of Gas Lighting.
Giornale del Genio Civile.
Glasers Annalen.
Golfing and Cycling Illustrated.
The Indian and Eastern Engineer.
L'Industrie.
Industries and Iron.
El Ingeniero Español.
Invention.
Inventor's Review.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
London Technical Education Gazette.
The Machinery Market.
The Marine Engineer.
The Mariner.
The Mechanical Engineer.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Public Health Engineer.
The Railway Engineer.
Railway Master Mechanic.
The Railway Review.
Revue générale des Chemins de fer.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
Street Railway Journal.
Tenders and Contracts.
The Textile Recorder.
Transport.

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The PRESIDENT moved the adoption of the Report of the Council with the statement of accounts, and invited any discussion thereon which the Members might wish to raise.

No remarks being offered, the motion was unanimously agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., .	London.

VICE-PRESIDENTS.

SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., .	London.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.

MEMBERS OF COUNCIL.

SIR WILLIAM ARROL, M.P., LL.D., ...	Glasgow.
SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., . .	London.
HENRY DAVEY, ...	London.
EDWARD B. ELLINGTON, ...	London.
THE RIGHT HON. WILLIAM J. PIRRIE, . . .	Belfast.
SIR THOMAS RICHARDSON, M.P., ...	Hartlepool.

For supplying the vacancy amongst the Members of Council, consequent upon the death of Mr. William Laird, the Council had appointed Mr. HENRY CHAPMAN as a Member of Council for the present year, his name being the next highest in the voting for the election at this Meeting. Agreeably with the Articles of Association, he would retire at the next Annual General Meeting, and would be eligible for re-election.

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The Council for the present year would therefore be as follows:—

PRESIDENT.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., ...	London.

PAST-PRESIDENTS.

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., . .	Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., ...	London.
SIR EDWARD H. CARBUTT, BART., . . .	London.
JEREMIAH HEAD, ...	London.
SAMUEL WAITE JOHNSON, ...	Derby.
ALEXANDER B. W. KENNEDY, LL.D., F.R.S., .	London.
E. WINDSOR RICHARDS, ...	Caerleon.
JOHN ROBINSON, ...	Leek.
PERCY G. B. WESTMACOTT, ...	Ascot.

VICE-PRESIDENTS.

SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., ...	London.
ARTHUR KEEN, ...	Birmingham.
EDWARD P. MARTIN, ...	Dowlais.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.
J. HARTLEY WICKSTEED, ...	Leeds.

MEMBERS OF COUNCIL.

SIR WILLIAM ARROL, M.P., LL.D., . .	Glasgow.
JOHN A. F. ASPINALL, ...	Horwich.
SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S.,	London.
HENRY CHAPMAN, ...	London.
HENRY DAVEY, ...	London.

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WILLIAM DEAN,	Swindon.
BRYAN DONKIN,	London.
EDWARD B. ELLINGTON,	London.
H. GRAHAM HARRIS,	London.
JOHN G. MAIR-RUMLEY,	London.
HENRY D. MARSHALL,	Gainsborough.
THE RIGHT HON. WILLIAM J. PIRRIE,	Belfast.
SIR THOMAS RICHARDSON, M.P.,	Hartlepool.
JOHN I. THORNYCROFT, F.R.S.,	London.
A. TANNETT WALKER,	Leeds.

Mr. SAMUEL W. JOHNSON said the time had now come when he had to retire from the office of President of the Institution. He had much pleasure in asking Sir William White to take that position. The Institution could not possibly have a better occupant of the chair, especially considering the duties that would have to be fulfilled during the coming year. The Institution House would have to be formally opened; and the members would all have an opportunity of seeing something of the ships of the Royal Navy when they went to the Summer Meeting in Plymouth. All the members of the Institution were expecting a particularly pleasant and instructive year under the guidance of their new President. He had great pleasure therefore in now asking Sir William H. White to take the presidential chair of the Institution.

SIR WILLIAM H. WHITE, on taking the chair as President, thanked the Members most sincerely for the great honour they had done him in electing him to this office, and assured them that to the best of his ability he should serve the interests of the Institution. It might be, it possibly would be, that other engagements which required some considerable time and thought would prevent his doing all he should wish in the service of the Institution; but he begged the Members to believe that, whatever the result might be, he should aim to do his best. There was one passage in the Report of the Council, of which he deeply felt the truth: namely the regret

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which all the Members must experience, and he personally perhaps most of all, that Mr. Johnson had not seen his way to continue to act as President of the Institution for another year. He assured Mr. Johnson, and he assured the Members, that he most heartily regretted that decision, partly on personal grounds, but still more for the sake of the Institution, which both Mr. Johnson and himself desired to serve.

SIR FREDERICK BRAMWELL, Bart., Past-President, believed it was his duty to obey the order of their new President, and thereby to set an example to all the younger men present; there were no older men present he thought to whom he could set an example. The order which had been given to him was one that ought to be most gratifying, namely to move a vote of thanks to their retiring President, Mr. Johnson. It would indeed be most gratifying, if he felt competent to fulfil it; but unhappily he did not, having himself had personally so little experience of his guidance of the Institution during the past year, as unfortunately he had himself been laid on the shelf, and for several months his doctor had not suffered him to come near this Institution or any other society; and therefore his personal acquaintance with the work of their ex-President, he was sorry to say, was extremely small. But there were some representations which were spread abroad by common report, of so strong a character and so well set out, that he felt as if he had been present, and he knew they might be taken as true. Having regard to such representations, and to his acquaintance with Mr. Johnson before his presidency, he was perfectly certain he should be only expressing the wishes and meeting with the approbation of all the Members present, in moving that a most hearty vote of thanks be given to Mr. Johnson for the way in which he had conducted the business of the Institution during his year of office. He had heard especially that the visit to Derby had proved all that could be desired, that Mr. Johnson's exertions there had been unremitting, that he was a power in that neighbourhood, and had opened places otherwise secret, and had caused the Institution to receive a most cordial welcome, and that in every way the Summer Meeting held

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(Sir Frederick Bramwell, Bart.)

there under his auspices had been a great success. Mr. Johnson had also had much labour in connection with the completion of the building in which they were now assembled for the first time tonight. He did not wish to call his friend Sir William White a cuckoo; but one man had built the nest, and another was come to enjoy it. The labour in connection with the building had been heavy, and it had been carried out, as everything else had been carried out, to the entire satisfaction of the Members. He would therefore move that a most hearty vote of thanks be given to Mr. Johnson, the retiring President, for the efficient manner in which he had in every way carried out his work as President of the Institution.

SIR EDWARD H. CARBUTT, Bart., Past-President, said the seconder of a motion proposed by Sir Frederick Bramwell, who was a past master in making speeches, found everything had been made easy for him, with little need for any effort on his own part. He had himself had the pleasure of knowing Mr. Johnson perhaps longer than any one else in the room, having watched his career from the years when he was himself a young man serving his time on the Midland Railway, and when Mr. Johnson was on the Great Northern Railway at Peterborough. In those early days all the young engineers already looked up to him, and talked about what he was going to do; for even then he had made his mark in the railway world. Since that time, now more than forty years ago, he had been in charge of the locomotive department on several other railways, especially on the Midland Railway for the past quarter of a century. As was well known, he had done everything that could possibly be done to serve the public on the Midland Railway, by making engines which could keep time and could carry the increasing traffic. Sir Frederick Bramwell had alluded to the princely reception accorded to the Members at Derby at the Summer Meeting. No one could have done more in securing such a reception than Mr. Johnson had done; and he felt sure the Members would all wish him long life and prosperity, and thank him for having been the President for one year, only regretting that his modesty had

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prevented him from continuing for another year. He had great pleasure in seconding the vote of thanks proposed by Sir Frederick Bramwell.

The resolution was carried with applause.

Mr. JOHNSON was deeply sensible of the kind eulogies which had come from Sir Frederick Bramwell, and of the warm manner in which the resolution had been seconded by his friend Sir Edward Carbutt. The position which he had held for the last year he had regarded as an exceedingly great honour; personally he did not desire any honour beyond it. If he had in any way contributed, in however small a degree, to maintain the prestige of the presidency and the interests of the Institution, he was amply rewarded. As the Members might know, the duties of the presidential chair were somewhat onerous; and as his presidential year happened to comprise a change of secretary and the finishing of a new building, and several other matters coincident therewith, it had naturally been a time of considerable activity for himself as President of the Institution. He should have been delighted to continue, as the Council desired, for a second year, had he felt that it would be consistent with the many other duties which he had to carry out. He thanked the Members most sincerely for the hearty way in which they had passed the resolution proposed by Sir Frederick Bramwell.

The PRESIDENT reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

Mr. THOMAS ASHBURY moved:—"That Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year at the same remuneration as last year, namely Twenty-five Guineas."

Mr. JOHN ETHERINGTON seconded the motion, which was carried unanimously.

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The "Fifth Report to the Alloys Research Committee: Steel;" by SIR WILLIAM C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S., Honorary Life Member, was then read and partly discussed.

Shortly before Ten o'clock the Discussion was adjourned to the following evening. The attendance was 229 Members and 89 Visitors.

The ADJOURNED MEETING was held in the House of the Institution, St. James's Park, London, on Friday, 10th February 1899, at Half-past Seven o'clock p.m.; SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Discussion upon the "Fifth Report to the Alloys Research Committee: Steel;" by SIR WILLIAM C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S., Honorary Life Member, was resumed and concluded.

The following Paper was then read and discussed:—

"Machinery for Book and General Printing;" by Mr. WILLIAM POWRIE, Member, of London.

The Meeting then terminated shortly before Ten o'clock. The attendance was 124 Members and 91 Visitors.

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FIFTH REPORT* TO THE ALLOYS RESEARCH COMMITTEE: STEEL.

By Sir William C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S.,
Honorary Life Member.

Before dealing with the subject to which this Report is devoted, the author would point out that the Research Committees of this Institution exerted a noteworthy influence in connection with the preliminary enquiry, the results of which have led to the recommendation that a National Physical Laboratory should be established. The report of the Council of the Royal Society recently published states that: "The deliberations of the Committee, appointed by Her Majesty's Treasury to consider the desirability of establishing a National Physical Laboratory, have resulted in an important addition to the responsibilities of the Royal Society. The Committee reported in favour of the establishment of such a Laboratory, and recommended that its control should be vested in the Royal Society, who should also nominate its governing body. Her Majesty's Government, having accepted the recommendations of the Committee, has invited the Royal Society to undertake the charge proposed in their report, including the administration of the funds which the Treasury has offered to furnish for the equipment and maintenance of the institution. The Council has decided in general terms to accept the trust offered to the Society." The author was a member of the Treasury Committee to which reference is made; and this Institution was also represented by Professor Kennedy and Mr. W. H. Maw, both of whom, as witnesses before the Committee,

* For the First, Second, Third, and Fourth Reports, *see* Proceedings 1891, page 543; 1893, page 102; 1895, page 238; and 1897, page 31.

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gave evidence of a highly important character. It may be added that, in the evidence which was taken by the National Physical Laboratory Committee, frequent reference was made to the work of the Alloys Research Committee. Lord Kelvin, who was also a witness, pointed out that continuing the investigation of alloys in a National Laboratory would be of great importance. The same view was taken in the evidence given by the President of the Institution of Civil Engineers, by the late Sir William Anderson, Professor Oliver Lodge, and several other witnesses. The research work therefore, on which the Committee of this Institution has been so long engaged, is fully and officially recognised, not only as being of national importance, but also as having rendered important service to industry.

Carburized Iron considered as a solution.—In the course of the last Report to the Committee, an attempt was made to connect the freezing-point curves of carburized iron. with those of ordinary alloys. The series of Reports as a whole had abundantly shown that alloys behave like saline solutions. It will be evident therefore that, if carburized iron, that is, steel and cast-iron, can be brought into line with ordinary solutions, a point of the utmost metallurgical importance will be gained. The series of results plotted in Plate 11 of the last Report* made it quite clear that the analogy of steel to an ordinary solution of salt is of the closest possible character, even if the evidence rests only on cooling curves taken in the usual way.

Recording Pyrometer.—It was certain however that the question is one of great complexity, and that a far more delicate method than that hitherto in use must be adopted, if conclusive and trustworthy results are to be obtained. The recording pyrometer, which has rendered such good service throughout this enquiry, had therefore to be rendered more sensitive than had hitherto been the case. The improvements described in the last Report consisted, it will be

* Proceedings 1897, pages 70 and 90.

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remembered, in employing a galvanometer so adjusted that the current produced by heating a thermo-junction attached to it would deflect the mirror through an angle of 50°. The current from the thermo-junction however was not allowed to pass unchecked through the galvanometer. It was opposed by a current from a large Clark cell, and the amount of the latter current could be accurately adjusted and measured by a potentiometer, so that only a small portion of the current from the thermo-junction really passed through the galvanometer. The result is shown in delicate curves, one of which was given in Plate 9 of the last Report (1897). The angular deflection of the galvanometer mirror is small, even at the highest temperatures: the sensitiveness of the instrument is not diminished, its resistance is not increased, but a portion of the current from the thermo-junction is balanced. It was found better to replace the astronomical clock of the older recorder by a water-clock consisting of a float moving upward between guides, and bearing a photographic plate. Since this description was published in 1897, enquiries have from time to time been made as to the details of the appliance. It is therefore shown in Plate 1 of the present Report, which represents that portion of the Research Laboratory where the new recorder is placed. The galvanometers are shown at G and G^1 with sources of light for illuminating their mirrors at L and L^1. The potentiometer is shown at B, and consists of four sets of resistance coils. The current flowing through the potentiometer is maintained by means of a Clark cell *g* with large electrodes. The water-clock H and its float F, the photographic plate P, and the hood K, are shown at the right of the drawing. S is the slit through which the rays of light from the mirrors of the galvanometers G G^1 are admitted to the sensitized plate. The arrangements of the galvanometers are shown diagrammatically in Figs. 1 and 2, page 38; and the system has been described in detail elsewhere * by Dr. Alfred Stansfield, who has assisted in conducting this series of investigations almost from their outset. As the result of many experiments, I adopted the following new method, of which a

* Philosophical Magazine, July 1898, page 59.

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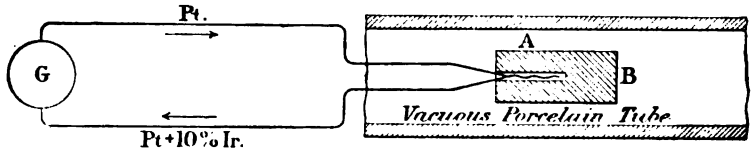
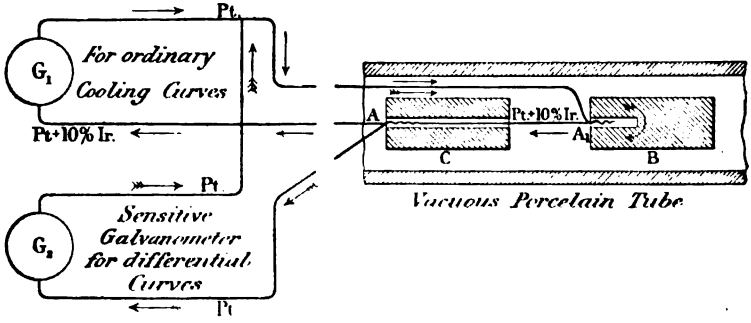
brief description will be sufficient. In the ordinary method, the twisted end of the thermo-junction A, Fig. 1, is placed in the heated mass of

Fig. 1.



metal B under examination, and its free ends are connected with the galvanometer G. In the new method, Fig. 2, two thermo-junctions A and A_1 are employed. One of these is placed in the piece

Fig. 2.



of metal B, and the other in a compensating piece of copper platinum or fire-clay C. A sensitive galvanometer G_2, connected to both thermo-junctions, measures on a large scale the difference between the temperatures of B and C; and magnified records of the evolutions of heat in B can thus be obtained, which are not affected by the general fall of temperature of the system. The actual temperature of the piece of metal B is simultaneously registered by the less sensitive galvanometer G_1 in the usual way. In the new method therefore the heat lost by the cooling mass of metal B, Fig. 2, is compensated or balanced by the heat lost by a mass of platinum C. The result is that the effect on the galvanometer G_2

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of any evolution of heat by the cooling mass B is greatly augmented. As has already been indicated, the heat suddenly evolved by the mass B of iron or steel, which is liable to molecular change, is not masked by the fact that the mass is itself rapidly losing heat; because the temperature of the entire system does not affect the sensitive galvanometer G_2, and the heat which is evolved by the mass B is free to make itself felt. Hence the curves recorded by the mirror of G_2 possess extraordinary sensitiveness. In Figs. 1 and 2 the arrows show the directions of the currents. Those with feathers indicate the direction of the current which is due to the difference of temperature; this difference is caused by the excess of heat in the iron B, as compared with the platinum C. The featherless arrows show the direction of the current through the unsensitive galvanometer G_1, which records ordinary cooling curves.

Reference to a special case, furnished by the cooling of electro-iron from a white heat, will serve to make this clear. A bead of electro-iron was deposited on a thermo-junction protruding from a glass tube into which the wires were fused. The iron was deposited from a solution of ferrous chloride which had been purified with scrupulous care. The anode was a plate of electro-iron; but the method of preparing the solution and depositing the iron need not be given, as it would break the continuity of this description. The deposited iron weighed five grammes = 0·18 ounce, and its appearance magnified 4 diameters is shown in Fig. 3 (page 40). A transverse section showing one of the wires of the thermo-junction, magnified 50 diameters, is shown in Fig. 4 (page 41). Its hardness was about that of fluor-spar, and when placed in water heated to 70° C. or 158° F. it freely evolved hydrogen, which ceased to come off after some hours. The bead of electro-iron was then arranged as shown in Fig. 2, and was placed in a porcelain tube glazed inside and out, and rendered vacuous by the aid of a mercurial pump, which also enabled the gas evolved from the iron to be collected. More hydrogen was freely evolved as the portion of the tube containing the iron was gradually heated; but, although the evolution of gas never absolutely ceased, the amount of hydrogen

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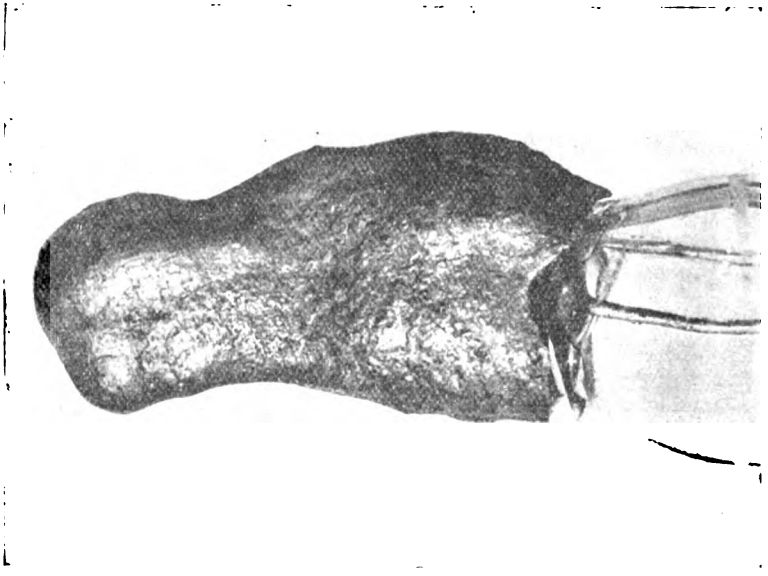
delivered by the mercurial pump was very small when the iron attained a temperature of some 1,300° C. or 2,370° F.

A cooling curve of this iron after four successive heatings is shown in Plate 2, on the actual scale on which it was recorded; and it is at once evident that at least three hitherto unobserved points are

Fig. 3.—*Electro-Iron Bead deposited upon Thermo-junction, magnified 4 diameters.*



w w = wires of thermo-junction. *g g* = glass.

here revealed. The co-ordinates are time and temperature, as usual; but the temperature represents on a large scale molecular evolutions of heat, and not the temperature of the mass under examination. There is at A the point at 1,132° C. or 2,069° F., which was first observed by my friend and former student, Dr. E. J. Ball. Then at B there is the ordinary Ar 3 of Osmond, which in this case occurs, not as in mild steel at the normal temperature of 850° C. or 1,562° F., but at 895° C. or 1,643° F. When the mass continues to cool down,

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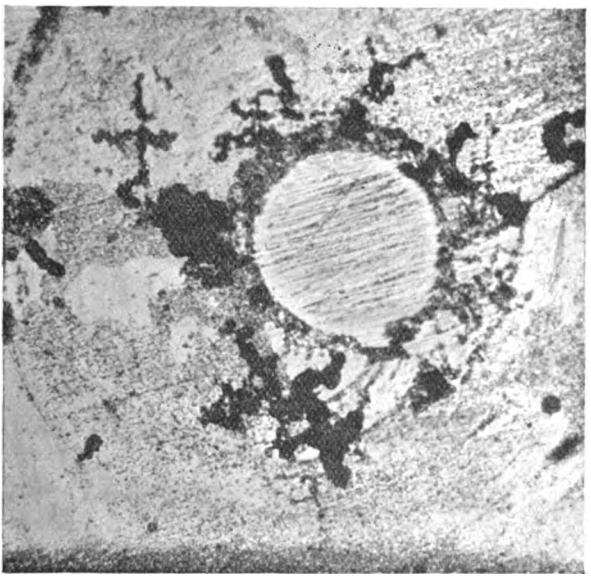
there is, as was anticipated, the point Ar 2, which in this case occurs at 766° C. or 1,411° F. The carbon point Ar 1 could not be expected to occur in iron of so high a degree of purity, and it does not exist; but there is evidence of evolution of heat at a point which I believe to be between 550° and 600° C. or 1,020° and 1,110° F. It is difficult to fix this point accurately; it seems to vary somewhat in

Fig. 4.—*Transverse Section of Electro-Iron Bead through Wire of Thermo-junction, magnified* 50 *diameters.*



successive curves. The next point, at which heat evolved, is a new one of extraordinary interest. It occurs between 450° and 500° C. or 840° and 930° F.; and evidence will subsequently be adduced to show that it is connected with the retention of hydrogen by the mass of iron, even though it had been heated to 1,300° C. or 2,370° F. Finally there is a small evolution of heat at about 261° C. or 502° F., that is, at a temperature of no less than 400° C. or 720° F. below redness. The significance of these new points will now be considered.

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Iron and Hydrogen.—It will first be desirable to give a brief summary of what is known as to the relations of hydrogen and iron. The late Professor Graham proved, so long ago as 1866, not only that hydrogen would freely penetrate tubes of iron at a red heat, but also that iron would, in cooling from redness in an atmosphere of hydrogen, occlude about 0·46 of its volume of the gas.* Later Cailletet† decomposed electrolytically a solution of ferrous chloride rendered neutral by the addition of ammonia, and obtained brilliant crystals of iron, which were sufficiently hard to scratch glass, and contained 0·028 per cent. of hydrogen. Johnson, Hughes, Baedeker, Ledebur, have all recorded‡ the fact that, when iron is attacked by dilute sulphuric or hydrochloric acid, it retains hydrogen.

My own experience, extending from the year 1870, when the late M. H. de Jacobi, of St. Petersburg, first taught me the method of depositing electro-iron, is to the effect that, although iron electrolytically deposited may scratch glass, it is not always deposited in the hard form; and this fact is generally known. I have elsewhere§ shown that the iron as deposited breaks with a tension of 2·7 tons per square inch, but that annealing at 800° C. or 1,470° F. raises the tenacity to 15·5 tons per square inch.

The experiments of Müller, which have been confirmed by Stead, on the gases released from ingots of iron and steel by drilling them, show the vast importance of the relations subsisting between iron and steel and the gases they occlude. It is strange however that, although in the Bessemer converter torrents of air charged with a comparatively small amount of aqueous vapour pass through the molten metal, the hydrogen is retained by the solid metal in far greater proportion than either the nitrogen or the carbonic oxide.

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* Graham, Collected Works, page 279.

† Comptes Rendus, vol. lxxx, page 319.

‡ Johnson, Proceedings of the Royal Society, vol. xxiii, 1875, page 168; Hughes, Journal of the Society of Telegraph Engineers, 1880, page 163; Baedeker, Zeitschrift des Vereines deutscher Ingenieure, 1888, page 186; Ledebur, Stahl und Eisen, 1887, page 681; 1889, page 745.

§ Journal of the Iron and Steel Institute, 1887, No. I, page 71.

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We have yet to take into account the amount of argon which passes through the metal in the course of an ordinary Bessemer blow.

In connection with the occlusion of gases in pig-iron, steel, and wrought-iron, the excellent work of Parry must be especially mentioned, in which he showed how persistently iron retains hydrogen.* Professor Arnold pointed out † in 1893 that in fused wrought-iron and in Swedish iron the point Ar 3 of recalescence occurs "much more sharply between narrower limits of temperature" when hydrogen and other occluded gases are removed.

The present investigation places the relations of iron and hydrogen in a new light. As already stated, the cooling curve given in Plate 2 shows the existence of two distinct evolutions of heat, which occur at about 487° and 261° C., or 908° and 502° F. These points in the cooling curve were recorded after the electro-iron had been heated in vacuo to 1,300° C. or 2,370° F. three successive times; but after repeated heatings of the metal in vacuo they become so small that it is impossible to identify them with certainty. There would therefore seem to be but little doubt that they are due to the presence of hydrogen occluded in the iron. The upper point at 487° C. or 908° F. may represent the separation of a hydride of iron from solid solution in the mass of iron; and the lower point at 261° C. or 502° F. may be the corresponding eutectic point.

It is remarkable that repeated heatings and coolings of low-carbon and electro-deposited iron in vacuo reduce the magnitude of all the now well-known molecular changes—Ar 1, Ar 2, Ar 3—as indicated on the cooling curves. The exhausted electro-iron may be re-charged with electrolytic hydrogen, by making it the negative electrode of a battery decomposing acidulated water. If the re-charged iron be heated in vacuo as already described, it will be found that the evolutions of heat in cooling, and consequently the points on the curves, will be restored to their original magnitude. As regards the two new hydrogen points, the upper one at about 487° C. or 908° F. is partially restored by re-charging the iron with electrolytic hydrogen,

* Journal of the Iron and Steel Institute, 1873, No. I, page 429; and 1874, No. I, page 92; and 1881, No. I, page 183.

† Second Report, Proceedings 1893, page 159.

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but the lower point at 261° C. or 502° F. is not. These results, which suggest that the molecular changes in iron are dependent upon, or are influenced by, the presence of small quantities of hydrogen, demand most careful study. Some experiments which I have still in progress show that the relations between hydrogen and iron are far more complicated than they have hitherto been supposed to be.

Carburized Iron considered as a Solid Solution.—The provision of this new and highly sensitive method of recording made it possible to resume that part of the investigation relating to the study of carburized iron, considered as a solid solution, the nature of which was briefly indicated in the last Report. It was therein stated that the curves shown in Plate 11 of that Report (1897) were the freezing-point curves of carburized iron, and served to show that this metal might be brought into line with ordinary saline solutions. It was also pointed out that such curves had been obtained quite independently in France by M. Osmond * so long ago as 1888, and more recently by M. Henri le Chatelier and by myself. The curves shown in Plate 11 (1897) constituted however the first attempt to embody in curves a comprehensive series of results. Since that Report was issued, the importance and urgency of the work have become more and more evident. The solution theory of iron and steel has formed the subject of an elaborate memoir, which was communicated to the Iron and Steel Institute by Baron Hanns von Jüptner, of Neuberg, Austria, in May last, and continued at the Autumn Meeting of the Institute. He pointed out that the data contained in Plate 11, just referred to, are far more conclusive than those which he himself had had at his disposal, "and allow of the hope of considerably enlarging our point of view, and of correcting our earlier conclusions in many respects." †

The constitution of salt solutions was studied by Guthrie so long ago as 1876; and his actual results ‡ for solutions of common salt in

* Annales des Mines, vol. xiv, 1888, pages 39 and 59.

† Journal of the Iron and Steel Institute, No. II, 1898, page 243.

‡ Guthrie, Philosophical Magazine, vol. i, 1876, page 359.

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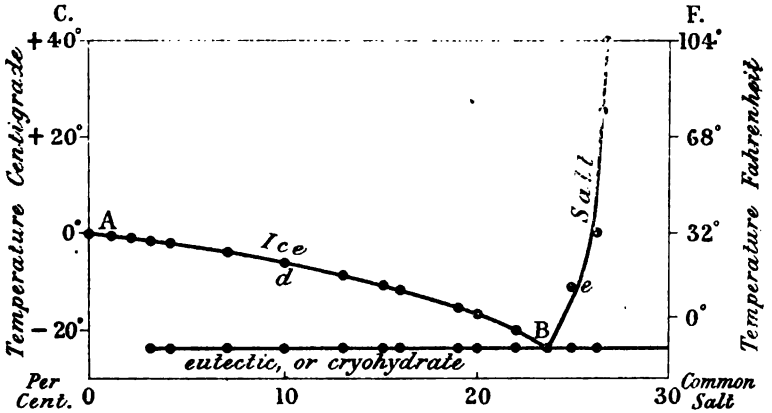
water are given in Fig. 5, in preference to the diagrammatic form by which they are sometimes represented. In order to render clear the nature of the curve given in the diagram, Plate 4, reference must be made to what happens when an ordinary solution of common salt in water is frozen. Fig. 5 shows how a thermometer plunged in the solution falls as the solution cools down. The dots along the lines are points of halt in the mercurial column; it is seen that in most cases there are two points for each stage of concentration.

Fig. 5. *Freezing-point Curves of solution of Common Salt in Water.*



The diagram consists of two branches, the one marked "ice," and the other "salt." It will be best explained by taking two solutions containing two definite amounts of salt on either side of the point B where the branches meet. If, for instance, a thermometer be placed in a solution of 10 per cent. of salt in water which is being slowly cooled down by means of an external freezing mixture, the mercury will halt in its fall at about −8° C. or 18° F.; this is due to the separation of pure salt-free ice. This gives the point *d* on the branch A B. The mercury then continues to fall until the temperature of −22° C. or − 8° F. is reached, and the cryo-hydrate or eutectic of ice and salt solidifies. This eutectic, as has been abundantly shown, consists merely of crystals of ice and of salt in juxtaposition. As the degree of concentration of salt in the

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original solution increases, the initial freezing point on the branch A B will be lower and lower, while the second freezing point always remains constant at −22° C. or − 8° F.; and when the solution contains 23·5 per cent. of salt, both freezing points coincide in the point B at −22° C. or −8° F.

The salt branch of the diagram is a very steep one, because the melting point of pure salt is above 700° C. or 1,300° F. Take on this branch a point *e*, representing water containing more salt than 23·5 per cent., say 25 per cent. In this case the first solid to separate on cooling is pure salt, and it does so at −12° C. or 10° F., which, for this degree of concentration of salt, is the first halting stage of the thermometer: the second is, as before, the solidification of the eutectic of salt and ice, which always has the same composition, and freezes at the same temperature, namely −22° C. or −8° F. The diagram therefore has two branches joining at B a horizontal line.

Carbon-Iron Solution.—The case of carburized iron is just the same, and is shown in the diagram, Plate 4. In conducting an investigation of this kind, it is most difficult to obtain a series of carburized irons in which the variation in the amount of carbon is progressive, while the amounts of other elements present in the iron either are maintained approximately constant, or vary only in a definite way. I have therefore much pleasure in expressing the great indebtedness of the Committee to Mr. John H. Darby of the Brymbo Steel Works, Wrexham, who most kindly prepared for me a series of small ingots of samples of metal which were successively ladled and cast at intervals of thirty minutes, during the working of a large hæmatite charge in a basic-lined Siemens furnace. These small ingots were analysed for me by Mr. F. W. Harbord, of the Royal Indian Engineering College, Cooper's Hill; his well-known skill as an analyst enables me to place the utmost confidence in the accuracy of the results, and my grateful thanks are due to him. These results are embodied in Table 11. I deliberately adopted a series that was not free from manganese, because a sufficient number of other samples of carburized iron had been prepared for comparison.

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TABLE 11.

Chemical Analyses of Steel Samples taken at intervals of 30 *minutes, during the working of a Hæmatite charge in a Basic Siemens Furnace, producing low-carbon steel. Brymbo Steel Works, Wrexham.*

† *See Plates* 8 *to* 11. †

Nos.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Arsenic.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
† 1	1·800	0·008	0·032	0·054	0·391	trace
2*	—	—	—	—	—	—
3	1·740	0·006	0·037	0·046	0·380	trace
4	1·451	0·006	0·029	0·023	0·340	0·004
† 5	1·461	0·007	0·038	0·025	0·340	0·002
6	1·234	trace	0·030	0·013	0·327	0·004
† 7	1·161	do.	0·030	0·016	0·290	trace
† 8	0·927	do.	0·025	0·013	0·293	0·004
9	0·912	do.	0·036	0·010	0·236	trace
† 10	0·821	do.	0·040	0·008	0·270	0·002
† 11	0·690	do.	0·038	0·009	0·220	0·004
† 12	0·540	do.	0·032	0·006	0·280	trace
13	0·434	do.	0·030	0·009	0·270	do.
† 14	0·342	do.	0·032	0·006	0·270	0·003
15	0·160	do.	0·037	0·008	0·240	trace
16	0·145	do.	0·041	0·006	0·250	do.
17	0·102	do.	0·037	0·008	0·230	do.
18*	—	—	—	—	—	—
19	0·070	trace	0·035	0·008	0·244	trace
20*	—	—	—	—	—	—
† 21	0·097	trace	0·030	0·007	0·220	0·004
22*	—	—	—	—	—	—
23	0·108	trace	0·033	0·005	0·240	trace
24	0·101	do.	0·034	0·004	0·217	do.
25	0·078	do.	0·033	0·007	0·217	do.

* Nos. 2, 18, 20, and 22 were not analysed.

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In the curve now presented to the Institution in Plate 4, in which the letters and general form are the same as in Plate 11 of the fourth Report (1897), an attempt is made to represent the constitution of carburized iron so far as it is at present known. The curve has two main branches A B and B D, meeting at B in the horizontal line *a c*. The line A B corresponds with the separation of pure ice in the diagram, Fig. 5 (page 45), while the line B D corresponds with the separation of salt. In the iron-carbon diagram the line A B indicates the "freezing" of iron, while the line B D denotes the separation of graphite. There is this difference however between the ice and the iron; the latter, on account of the high temperature at which it melts, still retains a certain amount of carbon after it has become solid. Hence there is a *solid* solution of iron and carbon, and this introduces further complications when the iron has cooled to a temperature at which it is no longer capable of retaining dissolved carbon.

First as regards electro-iron, which possesses a high degree of purity, suppose it to be in fusion, and well above its melting point. As the liquid mass cools down, it solidifies; and the point of solidification may be taken to be about 1,600° C. or 2,900° F., although this has not been determined with accuracy. When the iron has become solid, it exists in a plastic state, to which the name of γ iron has been given by Osmond; and while it is in this state it is capable of dissolving between 0·8 and 0·9 per cent. of carbon at 700° C. or 1,300° F., and rather more at higher temperatures; at 1,000° C. or 1,800° F., for instance, it would dissolve about 1·5 per cent. of carbon. It must be borne in mind however that the solubility of a substance depends on the form in which it is presented to the solvent; thus carbon in the form of ordinary graphite has a much lower degree of solubility at certain temperatures than carbon in the combined form known as "cementite." This suggests a reason why steel contains more combined carbon than slowly cooled pig-iron.

As pig-iron cools down, graphite falls out of solution when the temperature of the eutectic *a c* is reached: that is, the liquid eutectic of carbon and iron solidifies along the line *a c*. The amount of graphite, in any variety of pig-iron which contains up to about

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4 per cent. of carbon, will be indicated by the amount of heat evolved at this temperature, namely 1,120° C. or 2,048° F. In pig-irons containing more than 4 per cent. of carbon, an increasing amount of graphite appears on the upper branch B D. The "combined carbon" is mainly the carbon retained by the iron which solidifies on the line A B, though of course the iron which solidifies on the eutectic line *a c* also retains some carbon.

In Plate 4 are added three hypothetical lines, B*y*, *yv*, and *xyz*. B*y* shows the possible separation and solidification of iron in white iron, and is a continuation of the line AB; *yv* represents the possible separation of cementite in fused white iron; while the horizontal line *xyz* indicates the possible position of the solidification of the iron-cementite eutectic in white iron. This important addition to the curve was suggested to me by Professor Henri le Chatelier, to whom my best acknowledgments are due.

Changes in Solidified Carburized Iron.—The changes which have hitherto been considered relate to the solidification of either carbon-free (electro) iron or carburized iron. In all that follows, changes in *solid* carburized iron are alone considered.

When pure γ iron cools to the point G in the diagram, Plate 5—namely 890° C. or 1,634° F., or Ar 3—it undergoes a change to β iron, and the change is attended with an evolution of a considerable amount of heat. Like γ iron, β iron is non-magnetic, but it is much less capable of holding carbon in solid solution than γ iron. As the iron cools down to the point M—namely 770° C. or 1,418° F., or Ar 2—a further change takes place to α iron, which is magnetic. Much heat is evolved at Ar 2, but less suddenly than at Ar 3 (890° C. or 1,634° F.), probably because the iron is less mobile at the lower temperature (770° C. or 1,418 F.). As β iron dissolves less than 0·1 per cent. of carbon, the influence of carbon upon iron is practically eliminated at temperatures below the point G of the change to β iron. For this reason the line M O must be horizontal, as in the later work it has been found to be.

Iron containing about 0·2 per cent. of carbon may next be considered. It solidifies at a temperature a little lower than the

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melting point of pure iron, and the whole of the carbon remains in solution in the solid γ iron. There is therefore no liquid carbon-iron eutectic present to solidify at 1,120° C. or 2,048° F. When the iron containing about 0·2 per cent. of carbon cools still further, the evolution of heat known as Ar 3 occurs at about 830° C. or 1,526° F. The Ar 3 point has been lowered by the presence of carbon, in the same way that the freezing point of water is lowered by the addition of salt; and, just as in the salt solution, pure iron, which corresponds with ice, crystallises out, and the temperature continues to fall until at a definite temperature the whole of the still liquid solution solidifies. Thus, in the solid solution of 0·2 per cent. of carbon in γ iron, pure iron separates out of the solution and crystallises as β iron, forming ferrite. The temperature still continues to fall, until at about 690° C. or 1,274° F. the rest of the solution is broken up, forming pearlite. The iron changes from γ to β and then to α iron, while the carbon separates as cementite, Fe_3C. This separation of the carbon as a compound is analogous to the separation of copper sulphate from a solution, as the salt retains a definite amount of water of crystallisation.

Meanwhile the iron which separated as β iron at 830° C. or 1,526° F. has undergone another change to α iron at 770° C. or 1,418° F., the Ar 2 point. As β iron is free from carbon, the temperature of its change to α iron (Ar 2) is unaffected by the carbon contents of the steel as a whole.

In steel containing 0·6 per cent. of carbon the Ar 3 point has become depressed to about 720° C. or 1,328° F., so that all the iron remains in the γ form; when however this temperature is reached, pure iron or ferrite separates out, changing from the γ to the β and immediately to the α form. The rest of the iron remains in solution with the carbon until about 690° C. or 1,274° F. is reached.

The hypothetical lines EK and KL in Plate 5 indicate the separation respectively of cementite and of ferrite from a solid solution of highly carburized iron. If there is less carbon than 4·25 per cent., cementite will separate; but if there is more, ferrite separates.

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The sensitive method already described of recording the cooling curves has revealed the existence of a new point at which heat is evolved as iron cools down. This point occurs at about 600° C. or 1,100° F.; it may be premature to give it a definite symbol, but adopting M. Osmond's scheme of nomenclature it would be Ar 0. It appears to be the beginning of a comparatively slight molecular change which is not completed suddenly, but occurs over a range of 100° C. or 180° F. This change is also accompanied by a change in magnetic properties, for at this temperature of 600° C. or 1,100° F. Dr. D. K. Morris * has already decided a change in the permeability of iron. In Plate 3 are shown four of these delicate differential cooling curves from samples of steel containing severally 0·540, 0·342, 0·160, and 0·102 per cent. of carbon.

Mechanical Properties of Carburized Iron considered in relation to the Solubility (or Freezing-point) curves.—In the last Report † it was shown that it is possible to trace the relation between the freezing-point curve of the brasses and the curves which represent their mechanical properties of tenacity and extensibility. In the diagrams, Plates 4 and 5, the abscissae show the percentages of carbon for all the curves, while the ordinates represent temperatures. If a vertical scale of tensile strength were attached to Plate 5, and a curve of tensile strengths of annealed steel were to be plotted, it would be found that the point of maximum strength coincided very closely with the solid eutectic of iron and carbide which corresponds with 0·9 per cent. of carbon. The tenacity and freezing-point curves are directly and closely related; but Plates 4 and 5 are already so full that it is considered undesirable to plot the tenacity curve thereon in addition.

At the outset a grave difficulty is presented; the effect of varying amounts of carbon on the tenacity and extensibility of pure iron is not as yet known: that is, the presence of other elements intervenes and complicates the effect produced by carbon. It is only necessary

* Philosophical Magazine, part II, 1897, page 213, and Plates on pages 250–1.

† Fourth Report, Proceedings 1897, page 43.

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to glance at such a Table as that given in the classical work of Professor Howe * in order to see with what great difficulties the question is beset. Professor Howe gives the limits within which the tenacity of iron containing from 0·05 to 1·30 per cent. of carbon probably varies. The degree of carburization corresponding with the greatest strength is of the utmost importance, and fortunately the investigations of Professor Arnold are available. He had studied the effect of carbon on iron of a high degree of purity; and a "bent lath" curve, passing through all the points he gives for the series of annealed steels, fixes the maximum tensile strength at about 0·9 per cent. of carbon, which is very close to the composition of the eutectic 0·89 per cent. of carbon. Professor Arnold's value for these critical points in the curve of tenacity may safely be adopted for annealed steels; but, as he points out, the same series of steels in the "normal" state as received from the rolls give considerably higher results, and in these the point of maximum tensile strength occurs in steel containing 1·2 per cent. of carbon.

In the brasses (Plate 3 of the fourth Report, 1897) the point of maximum tensile strength occurs in the alloy which has a single solidifying point. In the same way, in the carbon-iron series the point of maximum tensile strength occurs in the alloy which in cooling has all the heat evolved at a single point. In the carbon-iron series it is not, as it is in the brasses, the *initial* freezing point which determines the strength, but the arrangement of the mass long after it has become solid, that is, when it is in *the form of solid solution.*

Evidence afforded by the Microscope.—If carburized iron is a solution capable of being either liquid or "frozen," it might be anticipated that the constituents of the solid solutions would be recognizable by the microscope, just as individual crystallized salts grouped together can be distinguished by suitable magnification. Patient research conducted with the aid of the microscope, beginning with the work of Sorby in 1864, has during the last thirty-five years proved that this is the case. Professor Arnold also has

* "Metallurgy of Steel," page 14. New York, 1890.

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recently published some beautiful coloured drawings illustrating the micro-chemistry of cementation.*

Carburized Iron considered as a Solution.—It has been already pointed out that a frozen solution of ice and salt consists of two constituents, either *ice* and *eutectic*, or *salt* and *eutectic*. Whether ice or salt separate will depend on the degree of concentration of the saline solution. In the same way solidified solutions of iron carbide and iron are also composed of either *iron* and *eutectic*, or *iron carbide* (Fe_3C) and *eutectic*, according to the amount of carbide present. It has been shown that all eutectics are finely divided mechanical mixtures, and Osmond has pointed out that the iron and iron-carbide eutectics are no exception.

It will be well to consider how the question of solution bears upon the constitution of carburized iron in common use. In order to do this the evidence of the microscope is all important. Micrographic methods have been so often described † that it is unnecessary to dwell upon them further than to state that, when highly polished surfaces of steel are treated with certain re-agents, some of the constituents, the carbides, become stained, while the iron retains its original colour.

For micrographic purposes, steel is viewed as if it were a rock with various minerals distributed through it, and mineralogical names are conveniently adopted for the constituents. Thus, iron free from carbon is called "Ferrite," which is left white and brilliant when the polished specimen is treated with either a very dilute solution of nitric acid or an infusion of liquorice. Strong nitric acid does not attack the ferrite; but this re-agent should not be used without great care. Very dilute solutions of nitric acid either in alcohol or in water develop the crystalline structure of the ferrite, as is shown in Figs. 11 and 12, Plate 6. Nitric acid etching however impairs the sharpness of the pearlite, and tends to produce porosity.

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* Journal of the Iron and Steel Institute, 1898, No. II, page 185.

† Roberts-Austen, "Introduction to the Study of Metallurgy," 1898, page 391, where a bibliography is given.

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"Cementite," another constituent of steel, is a carbide which corresponds with the formula Fe_3C. It remains bright after the polished section of steel is attacked by either iodine solution or an infusion of liquorice. It is hard, and stands in relief when the steel is polished with the finest rouge on parchment placed on a soft support, such as wood. Free "cementite" however occurs very rarely in low-carbon steel. The carbide in low-carbon steel usually assumes the form of "Pearlite," which is an intimate mixture of ferrite and cementite. It is a characteristic constituent of steel which has been slowly cooled from a high temperature; and if the steel contains about 0·9 per cent. of carbon, the mass will consist entirely of pearlite. It may be either lamellar or granular in structure. It may be coloured dark by iodine solution; and its presence is best revealed when the steel is polished in relief by the method which has just been indicated, and treated with a filtered infusion of liquorice root in cold water. It consists of lamellae, which are alternately hard and soft. Hardened steel appears to be composed of "Martensite," a system of interlacing crystalline fibres, which may readily be coloured by a tincture of iodine. Photographs of these various constituents will be referred to immediately. In all cases the illumination was vertical, and with three exceptions the sections were stained with an infusion of liquorice root. (*See description of Plates, pages* 55–59.)

In order to make clearer the nature of these main constituents of carburized iron, photo-micrographs may be directly appealed to. Pure iron or "ferrite," like pure ice, exhibits crystalline planes. But if only a minute proportion of carbon be present, even so little as 0·04 per cent., there may be, as Stead has shown, in such iron which has cooled slowly, evidence of carbide of iron as a cement between the grains. Such a section of iron, etched with 1 per cent. of nitric acid in alcohol, and magnified 140 diameters, is shown in Fig. 11, Plate 6.

In slowly cooled iron, which contains from 0·3 to 0·5 per cent. of carbon, the carbide will be concentrated into patches of pearlite set in ferrite, as is shown in the accompanying sketch *a*, Fig. 6, or in Fig. 13, Plate 6. Very high magnification, such as 1,000 diameters,

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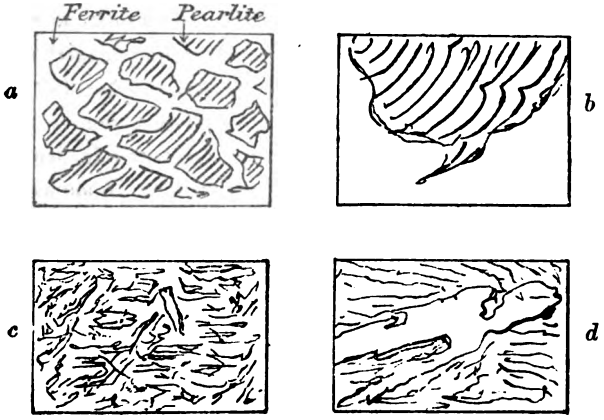
resolves these patches of pearlite into banded structures consisting of alternate laminae of hard carbide and soft ferrite, as shown in sketch *b*, Fig. 6, or in Fig. 15, Plate 6; the mass as a whole is called pearlite from its resemblance to "mother of pearl."

Fig. 6.



Martensite entirely. *Cementite patch in centre.*

Approximate magnifications:—
a = 200; *b* = 1,000; *c* = 800; *d* = 800 diameters.

Iron becomes saturated when the proportion of combined carbon is about 0·9 per cent.; and if such a metal has been slowly cooled, it will consist entirely of pearlite without any free ferrite, as shown in Fig. 15, Plate 6; while if the proportion of carbon exceeds 0·9 per cent., the carbide layers will show a tendency to run together into bands of cementite, which is shown white in *d*, Fig. 6, and light in Fig. 16, Plate 6. When a low-carbon steel contains much manganese, the area of the pearlite becomes large relatively to that of the ferrite, and the grains also increase in size. This is well shown in Fig. 14, Plate 6, which represents steel containing approximately the same percentage of carbon as Fig. 13, but considerably more manganese. When examined under a high power, the structure of the grain of pearlite in steel containing much manganese is almost invariably more minute than in steel containing but little of that metal.

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The appearance of carburized iron after rapid cooling, as in the operation of hardening steel, is widely different. A constituent known as "Martensite" appears; its general nature is shown in the sketch *c* (page 55), or in Fig. 19, Plate 7, which represents steel containing 0·54 per cent. of carbon after quenching in water from a temperature of 1,000° C. or 1,832° F. The "tempered" structure of such a steel somewhat resembles the last figure, and is shown in Fig. 20, Plate 7. If the proportion of carbon be still higher, say 1·5 per cent., and if the cooling be rapidly effected in iced brine, another constituent appears, which may be scratched with a hard needle, and to which M. Osmond, who discovered it, has given the name of "Austenite." Its general appearance is shown white in Fig. 22, Plate 7, magnified 850 diameters. By the great kindness of Professor Dewar I have been permitted to quench a high-carbon steel, heated to 1,000° C. or 1,832° F., in liquid air, the temperature of which is – 200° C. or – 328° F. The result is shown in Fig. 21, Plate 7, magnified 60 diameters; but, notwithstanding the extreme cold, the structure of the steel does not materially differ from that which would have been produced by allowing the metal to cool rapidly under ordinary atmospheric conditions, probably because a vaporized layer of air instantly forms and prevents the liquid air from coming in contact with the hot steel. Other constituents are called "Troostite" and "Sorbite"; they are modifications of cementite, but their consideration is beyond the limits of the present Report, though an example of Troostite is shown black in Fig. 18, Plate 7. Troostite is produced by quenching steel up to 0·4 per cent. of carbon at about 750° C. or 1,382 F°. Slag flaws which occur in steel and iron vary in appearance with their composition. In Fig. 17, Plate 7, is given a fairly typical slag-flaw, magnified 640 diameters; it occurred in a rail which broke on the road in India. The rail had previously withstood the mechanical tests well; and chemical analysis showed that it contained about 0·27 per cent. carbon and 0·71 per cent. manganese, the other constituents being present in very small quantities.

So far, only typical modes of occurrence have been considered; and specific cases may now be dealt with. For photo-micrographs a series has been selected either of cementation steels prepared in the

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laboratory or of the Brymbo series, the composition of which is given in Table 11 (page 47). The iron which formed the basis of the cementation series is given in Figs. 23 and 24, Plate 8. They show nearly carbon-free iron, containing only 0·07 per cent. of carbon, magnified 140 and 850 diameters. In Fig. 23 there are a few small patches of pearlite, which under the higher magnification in Fig. 24 reveal their true pearlite structure. Figs. 25 and 26 show one of the specimens lowest in carbon of the Brymbo series (Table 11, No. 21, page 47). The specimen contains 0·097 per cent. of carbon, and contains small patches of pearlite in a matrix of crystalline ferrite. As in the preceding case, these patches reveal a true pearlite structure under the higher magnification in Fig. 26. The above specimens, Figs. 23 to 26, were etched with alcohol containing 1 per cent. of nitric acid.

Figs. 27 and 28 show the effect of carburizing the iron given in Figs. 23 and 24. It will be seen that the structure is very different from that found in the rail steels, of which typical examples are given in Plates 14 and 15. Here the grains are nearly elliptical or circular, no trace being visible of the interlocking grains. The higher magnification in Fig. 28 shows fairly typical pearlite; but the laminæ are by no means so well formed as in some of the other specimens.

Figs. 29 and 30, Plate 9, also represent a preparation of cementation steel made in the laboratory. The grains in this are very small, in fact smaller than any other grains of the series, and have a more or less rounded shape. The higher power in Fig. 30 reveals good bold pearlite with well-developed laminæ. This specimen contains 0·3 per cent. of carbon. Figs. 31 and 32 show the structure of one of the Brymbo series (Table 11, No. 14, page 47), which is of similar composition to the last cementation steel, and contained 0·342 per cent. of carbon. The grains are rather larger than those of the last specimen, and the pearlite under higher magnification in Fig. 32 proved to be equally well formed. Figs. 33 and 34 show similar magnified sections of Brymbo steel No. 12, containing 0·54 per cent. of carbon. The grains are more angular than any yet seen in this series of steels; but none have been subjected to any mechanical

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treatment which would have caused the grains to interlock. The pearlite is quite typical of what should occur in pure steel containing this percentage of carbon.

Fig. 35, Plate 10, shows Brymbo steel No. 11, containing 0·69 per cent. of carbon, magnified 140 diameters. The grain here also is small. Fig. 36 is a cementation steel containing 0·552 per cent. of carbon, magnified 850 diameters. The pearlite is broad and well developed. The portion shown in the photograph is not quite typical, considering the amount of carbon, although in other portions of the specimen the ratio of ferrite to pearlite is much greater. Fig. 37 is a low power (140 diameters) of Brymbo No. 10, containing 0·821 per cent. of carbon. There is a certain amount of ferrite visible in the mass. Fig. 38 is a variety of steel of almost exactly the same composition as Brymbo No. 10, and has been subjected to the same thermal treatment; as will be seen, magnification of 850 diameters shows that nearly the whole mass consists of pearlite. Its carburization is close to the saturation point of carbon in iron. Figs. 39 and 40 are respectively low and high magnifications of Brymbo No. 8, which contains 0·927 per cent. of carbon. The lower power in Fig. 39 shows a more or less confused mass containing patches of cementite. When magnified 850 diameters in Fig. 40, the confused mass resolves itself into pearlite. In no part of the field does the cementite encircle the grains of pearlite.

Figs. 41 and 42, Plate 11, are preparations from Brymbo No. 7, containing 1·161 per cent. of carbon, and show very similar structures to the last; but much more cementite is present. Figs. 43 and 44 were prepared from Brymbo No. 5, containing 1·461 per cent. of carbon; unlike the two previous specimens, the cementite here completely surrounds the grains of pearlite, and might easily under a low power be mistaken for ferrite. The photograph at first sight is not unlike a highly manganiferous rail-steel, containing say 1·0 per cent. of manganese and 0·4 per cent. of carbon. Careful examination under the microscope shows that the cementite appears in relief, and has a high polish and must therefore be hard. Under a magnification of 850 diameters in Fig. 44 quite a different appearance presents itself; the material surrounding the grains in

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Fig. 43 is found to be disconnected, in fact made up of irregular patches, and not continuous as it would have been had it been ferrite. As seen in the photograph, this constituent exhibits all the characteristics of cementite. Figs. 45 and 46 show Brymbo No. 1, containing 1·8 per cent. of carbon. These photographs reveal all the peculiar characteristics of the previous specimen (Figs. 43 and 44), with the exception that the ratio of pearlite to cementite is much greater in Figs. 45 and 46, owing to the higher percentage of carbon.

Plate 12 is devoted to pure cast-irons under a magnification of 850 diameters. Fig. 47 is a white iron, containing 2·573 per cent. of combined and 0·190 per cent. of graphitic carbon; the structure is almost entirely made up of cementite and pearlite. Fig. 48 shows a grey cast-iron, containing 1·124 per cent. of combined and 2·640 per cent. of graphitic carbon; here the matrix is mainly composed of pearlite, with patches of cementite and graphite. Fig. 49 is a grey cast-iron prepared in the electric furnace; it contains about 4·02 per cent. of carbon, and is composed of cementite, graphite, and pearlite. Fig. 50 is also a grey cast-iron prepared in the electric furnace; this specimen is much softer than that shown in Fig. 49, the cementite in Fig. 49 being here replaced by ferrite, which contains a large number of minute octahedra; these stand in relief, and have all the appearance of small crystals of diamonds. Fig. 51 is another specimen of grey cast-iron prepared in the electric furnace; it shows a structure of which the matrix is composed of well-developed pearlite; the matrix contains a number of grains of ferrite and graphite, and the outlines of many of the graphite grains are much curved. Fig. 52 is a specimen of grey cast-iron, which has been carburized as highly as possible in the electric furnace; it contains about 5·2 per cent. of carbon, and is composed of ferrite, pearlite, and a large amount of graphite; the button of metal after carburization was very soft, and pieces were easily reduced to powder under the hammer.

The bearing of these considerations on industrial practice will now be dealt with. In iron containing 0·2 per cent. of carbon, which is being cooled slowly, the evolution of heat at 830° C. or 1,526° F. represents the formation of the pure ice of the

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iron-carbon series, or as it is called "ferrite." This pure iron undergoes a further molecular change on cooling down to 770° C. or 1,418° F., when it becomes magnetic. The formation of the pearlite shown in the diagram is indicated by the halt at about 690° C. or 1,274° F.

Among the carburized irons which are comparatively low in carbon, few members of the series are more important than those which lie between the points O and S in the diagram, Plate 5. They are widely used for steel rails, and contain from 0·3 to 0·8 per cent. of carbon. It is remarkable that the complexity of constitution indicated by the curves in Plate 5 is considerably lessened in this class of steel. In the cooling curve of a rail steel there are only two points of halt: the first, occurring between 700° and 750° C. or 1,300° and 1,380° F., represents both the separation of ferrite and the magnetic change; while the second halt, occurring at about 690° C. or 1,274° F., indicates the separation of the carbide "pearlite."

Application of Photo-micrography to the study of Steel Rails.—A preliminary treatment of an entire cross-section of a rail by dilute sulphuric acid affords much information as to the exact positions of the portions which it is desirable to subject to detailed examination. A transverse section about one inch in thickness is cut from a rail; one face is then carefully surfaced, and the back and edges of the section are covered with a suitable protecting varnish. The section is then placed with its unprotected surface upwards in a bath of dilute sulphuric acid (4 water to 1 acid) raised to a temperature of 60° C. or 140° F. The action of the acid is maintained for two hours, when the section is removed, washed in warm water, and dried. The appearance of the specimen is much improved by dipping the prepared surface in concentrated nitric acid, washing in water, and drying. It is probable that the whitish stains, which after the first treatment generally adhere to such a prepared surface of a rail section and impair its appearance for photographic purposes, are composed of carbide Fe_3C, which has not been dissolved by the sulphuric acid. This Fe_3C is rapidly dissolved by the nitric acid

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followed by washing, and a clean surface is left. The result of such preliminary treatment of a rail is to reveal either a minutely granular texture on the one hand, or a deeply pitted and furrowed structure on the other. Four such prepared sections are given in Plate 13. The extreme cases are represented by Fig. 53, which exhibits deep corrosion, and by Fig. 56, which is minutely granular and evenly attacked. Rails which are much corroded, as in Fig. 53, are often high in sulphur and phosphorus, low in manganese, but high in carbon. The corrosion indicates there has been much liquation or separation of the constituents of the ingot during solidification. This corroded structure is not inconsistent with durability in wear, nor with good results under the falling-weight test, even after prolonged wear. On the other hand, a finely granular rail, such as is shown in Fig. 56, usually indicates the presence of much manganese, that is, 0·9 per cent. or over. The tenacity of such a rail would be high, but its endurance under the falling-weight test would be low, and there is danger of a tendency to brittleness. Such a rail shows but little indication of the occurrence of liquation. From such etched sections it is easy to see which portion best deserves selection for the purpose of photo-micrography.

The photo-micrographs of each of the four transverse sections of rails shown in Plate 13 are given in Plates 14 and 15. They are arranged vertically, so that the photo-micrographs of rail 1 are Figs. 57, 59, and 61. The first photograph of each rail—Figs. 57, 58, 63, and 64—shows the structure of the exterior of the rail head, magnified 140 diameters. The second photograph in each set—Figs. 59, 60, 65, and 66—shows the interior of the head under the same magnification. The third—Figs. 61, 62, 67, and 68—shows the structure of a pearlite patch, magnified 850 diameters. Rail 1, which, as shown in Plate 13, was corroded unevenly in dilute sulphuric acid, revealed a structure that is generally characteristic of a good rail; the exterior is made up of small grains, Fig. 57, Plate 14, while the area of the ferrite is rather greater than that of the pearlite. In the interior, Fig. 59, the grains are larger, and the ratio of pearlite to ferrite is much greater than on the

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exterior of the rail. Under the high power, Fig. 61, the pearlite shows well-defined laminæ, which differ greatly from those occurring in highly manganiferous rails. Rail 2 contains rather less carbon and phosphorus than rail 1. It gave good results in use. As seen in Figs. 58 and 60, the structure is more homogeneous than in rail 1, and the grains are somewhat smaller. Under the high power, Fig. 62, the carbide areas are found to be made up of good broad pearlite. Rails 1 and 2 both gave remarkably good results under the falling-weight test; with a tup weighing 2,240 lbs. and bearings placed three feet apart, they did not break until the height of fall was increased to 27 feet; the same result was obtained in each, whether the worn head was placed up or down. Rail 3 contains less carbon and more manganese than either rail 1 or rail 2. As seen from the similarity of Figs. 63 and 65, Plate 15, the structure is fairly homogeneous, the black pearlite area in the interior of the rail head, Fig. 65, being only slightly in excess of that on the exterior, Fig. 63. As shown in Fig. 67, the pearlite is somewhat granular, and the laminæ are not well defined. Under the falling-weight test this rail gave most variable results, fracture taking place with heights of fall varying from 2 to 10 feet. Rail 4 contains the most manganese of the series. Figs. 64 and 66 show that the ratio of the carbide to the ferrite areas is greater than in any of the other three rails. The grain itself is also much larger. Under the high magnification in Fig. 68, the pearlite is seen to be a minutely granular variety, and is highly characteristic of the larger percentage of manganese. The rail has high tensile strength, but is not one which would be capable of withstanding sudden shock; under the falling-weight test it broke with a height of fall varying from 6 to 10 feet.

In Fig. 69, Plate 16, is shown the general distribution of pearlite and ferrite areas in the entire transverse section of a rail. The extent to which the size and nature of the grain vary in different parts of the section is also well shown in the magnified Figs. 70 to 75 which surround the rail section. From the same rail are given in Plate 17 four photo-micrographs obtained from portions of metal cut from corresponding parts of transverse sections of the rail, but at points no less than ten feet apart. Thus Fig. 76 is cut from the

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upper flange near the crop end of a rail; and its grain is slightly smaller than that shown in Fig. 77, which is from a corresponding point as regards the transverse section, but ten feet nearer the centre of the rail. Fig. 78 is from the interior of the lower flange of the crop end of the rail; and its grain is also smaller than that of a corresponding portion, Fig. 79, cut ten feet nearer the centre of the rail. It will be seen that, although in each case the grain nearer the centre of the rail is slightly larger than near the end, nevertheless the structures of the corresponding parts in the two transverse sections ten feet apart are closely similar. The smallness of the grain near the end of the rail in this example is undoubtedly due to the more rapid cooling of the end than of the centre. Even without making allowance for this fact, the difference in structure is not great: so that a transverse section cut from any part of the rail fairly represents the general structure of the rail throughout its length. The rail used in the preparation of Plates 16 and 17 is an exceptionally good one. The sections were given me by Mr. W. G. Kirkaldy; and the rail is one of six taken up near Misterton on the Great Northern and Great Eastern Joint Railway, between Doncaster and Gainsborough. It originally weighed 80 lbs. per yard, and after 17 years and 2 months wear weighed 77 lbs. Altogether about 50½ million tons of traffic had passed over it. The following are the results of the mechanical tests to which the rail was subjected:—tensile strength (bottom member) 45 tons per square inch; contraction of area at fracture 36 per cent.; extension in ten inches 18·8 per cent. The chemical analysis of the rail from metal cut near the head is as follows:—

	Per cent.
Iron (by difference)	98·389
Carbon	0·508
Silicon	0·091
Manganese	0·844
Sulphur	0·063
Arsenic	0·023
Copper	0·016
Phosphorus	0·066
	100·000

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The question of rail steel has been considered merely in relation to the position it occupies in the freezing-point curve of carburized iron; and no attempt has been made to deal with the subject with any approximation to exhaustiveness. The foregoing remarks however will serve to indicate the direction in which work may be conducted, more particularly in relation to photo-micrography.

Mr. Thomas Andrews, as is well known, has dealt at great length with the structure of rails, and has illustrated his observations by drawings,* and has devoted special attention to the question of flaws. The nature of flaws has also been recently treated in an important paper by Mr. Stead, † whose great skill as a photo-micrographist lends special interest to the photo-micrographs by which his paper is illustrated. With regard to the size of grain: the relative dimensions of the areas of pearlite and of ferrite, as well as the size of the granules, afford valuable indications as to the qualities of the rail, and as to its probable durability. It has been shown by Martens ‡ that the size of the grain increases with the temperature at which the rail was rolled: whereas the strength and extensibility of the rail increase when the size of the grain diminishes. Rolling at too high a temperature seems to produce large meshes of ferrite enclosing pearlite; but within certain limits the higher the temperature of rolling, the greater are the strength and durability of the rail. It will be obvious that steel of the same composition must be considered in such a generalisation.

Mr. Sauveur found that the tenacity of rolled steel varies inversely as the size of the grain. M. Osmond § has recently shown that the results arrived at by Mr. Sauveur and M. Ljamin, as regards the relation between the size of grain and the physical properties of

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* *Engineering*, vols. lxiii and lxiv (1897), and lxv (1898). "Microscopic internal flaws inducing fracture in steel." Reprinted from *Engineering*, 10, 17, and 24 July, 1896.

† Proceedings Cleveland Institution of Engineers, 14 Nov. 1898, page 12.

‡ Mittheilungen aus den Königlichen technischen Versuchs-anstalt, vol. xiv, 1896, page 89.

§ Metallographist, vol. ii, 1899, page 78.

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rolled steel, are not discordant. But it is necessary to compare steel of the same composition; for, speaking generally, the greater the amount of carbon and manganese in steel, the larger will be its grain and the greater its tenacity. For rails with transverse sleepers the falling-weight test appears to be more important than tensile tests. High tenacity is of course often accompanied by brittleness.

Effect of varying Thermal treatment on the structure of Steel.—Two varieties of steel were used to show the influence of thermal treatment. One was a low-carbon rail-steel, and the other a fairly pure die-steel higher in carbon. The metal cut from the low-carbon rail-steel shown in Plate 18 gave on analysis the following composition:—

	Per cent.
Iron (by difference)	98·828
Carbon	0·277
Silicon	0·006
Manganese	0·710
Sulphur	0·072
Arsenic	0 020
Phosphorus	0·087
	100·000

Fig. 80 is a photo-micrograph of a piece of this steel, magnified 850 diameters, which had been rolled at a bright red heat and allowed to cool slowly; here the pearlite has separated from the ferrite, while the laminæ of the pearlite are moderately well developed. Fig. 81 shows another sample of the same steel, which has been annealed for 18 hours at about 500° C. or 930° F.; here the carbide areas have contracted considerably, and mostly consist entirely of cementite. Fig. 82 shows the effect of heating this steel to 750° C. or 1,380° F., and quenching immediately in cold water; the carbide has partly separated out in the form of Troostite, which in this instance is of a ropey nature, and not much like that shown in Fig. 18, Plate 7; in Fig. 82 it is mostly embedded in a matrix of Martensite, as in Fig. 18. Fig. 83 is a photo-micrograph of a piece of the same steel, which has been quenched in water from a

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temperature of over 1,000° C. or 1,830° F.; the result is the interlacing crystalline fibres which constitute Martensite.

The die steel used for the preparation of Plate 19 gave on analysis the following composition:—

	Per cent.
Iron (by difference)	98·93
Carbon	0·82
Silicon	0·05
Manganese	0·10
Sulphur	trace
Copper	——
Phosphorus	——
	99·90

All the photo-micrographs in Plate 19 are magnified 850 diameters. Fig. 84 shows the structure of a sample which has been forged and slowly cooled; here broad well-defined pearlite is visible. Fig. 85 shows the effect of annealing a specimen for about five hours at a temperature of about 600° C. or 1,110° F. In Fig. 86 are well shown the large crystallites of Martensite, produced by heating such a steel to about 1,000° C. or 1,830° F., and quenching in water. Fig. 87 indicates the tempered structure of the hard steel shown in Fig. 86; it was produced by reheating the quenched specimen, Fig. 86, to straw colour, about 243° C. or 470° F., and quenching in water. Fig. 88 shows the effect of quenching this steel at a temperature of about 750° C. or 1,380° F. When dies and other thick pieces of steel are quenched at too low a temperature, it often happens that a granular structure is produced, although often only in the interior of the mass. Should the article be a die, it will probably "sink" during use, owing to the softness of the centre; and the difference in tension between the centre and the outside will render it liable to crack. Fig. 89 is a photo-micrograph of burnt steel; a piece of the slowly cooled steel was heated in a porcelain tube to considerably over 1,100° C. or 2,000° F., and allowed to cool slowly. The microscope revealed that the structure consisted of ferrite, free graphite, and pearlite. The steel would not harden under repeated quenchings, and showed all the characteristics of

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burnt steel. The cementite Fe_3C appears to become decomposed into ferrite and graphite.

Structure of Steel containing small percentages of Chromium.—Steel to which small quantities of ferro-chrome have been added has a much higher tensile strength, even after annealing, than ordinary steel of the same degree of carburization would have when similarly treated. When hardened in the usual way by quenching, the hardness penetrates more deeply in the chrome steel than in ordinary steel of the same carburization. These changes in mechanical properties it was thought would also be accompanied by a change of structure. Three kinds of excellent chrome steel were sent me by Mr. Webb from Crewe; and subsequent investigation proved that their structures, especially in the slowly cooled specimens, differed greatly from those of ordinary steel of the same carburization. Figs. 90 and 91, Plate 20, show respectively the structures, magnified 850 diameters, of a soft and a hard specimen of chrome steel, containing 0·32 per cent. of chromium and 0·44 per cent. of carbon; such a steel is well suited for tires and axles. In the soft specimen, Fig. 90, the carbide patches appear to be almost structureless, and the pearlite laminæ are very small. The crystallites constituting the Martensite in the hardened specimen, Fig. 91, are about normal for ordinary steel of the same carburization treated under similar conditions. In Figs. 92 and 93 are shown respectively the structures of soft and hard tool-steel, containing 0·46 per cent. of chromium and 0·85 per cent. of carbon. The soft structure, Fig. 92, greatly resembles the tempered structure of ordinary steel, and is composed of a minutely granular pearlite. The hard structure, Fig. 93, is that of Martensite; but the needle-like crystallites are smaller than those of a normal steel containing the same amount of carbon: compare Figs. 84 and 86, Plate 19. Soft and hard specimens of chrome spring-steel, containing 0·17 per cent. of chromium and 0·78 per cent. of carbon, were also prepared; and their appearance under the microscope is shown in Figs. 94 and 95, Plate 20. The soft specimen, Fig. 94, is mainly made up of extremely minute pearlite, with a few small patches of ferrite. The

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hard specimen, Fig. 95, is composed of Martensite, the crystallites of which are smaller than those that would be produced in a normal steel of the same carburization if quenched under the same conditions.

Although these six specimens of steel contained such a small percentage of chromium, they were nevertheless found to be much harder in the slowly cooled state, Figs. 90–92–94, than ordinary steel similarly treated would have been. The quenched specimens, Figs. 91–93–95, were harder than quenched ordinary steel of the same carbon percentage; but this difference of hardness is not nearly so well marked in these three quenched varieties as it is in the three slowly cooled. From the above it is evident that the presence of chromium in small quantities tends to make the combined carbon more soluble, by replacing some of the iron in the iron carbide. This would support the view that in chrome steel the carbide is not entirely present as Fe_3C.

Discussion.

Sir WILLIAM C. ROBERTS-AUSTEN wished to express his deep sense of the loss that the Alloys Research Committee had sustained by the death of their chairman, Sir William Anderson. Adequate expressions of the truest sympathy had already, he knew, been communicated to Sir William Anderson's family; but on the part of those who were conducting the research he should like to say how deeply it was regretted that Sir William was no longer with them, because he had initiated this particular research into alloys, and had

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taken the warmest interest in it as long as he lived. To the new President of the Institution he was most grateful for having accepted the chairmanship of the Committee. Had it not been for this fact, he feared he should himself have been discouraged from continuing the work any longer, because it made such severe demands upon his leisure. But with Sir William White as their chairman he hoped the Committee would be able to furnish at least one more Report. The present fifth Report he had been asked to prepare in readiness for this first meeting in the new building; and he felt it was a most flattering request, which however had resulted in the Report being somewhat hurriedly prepared. He wished also to say a word of grateful thanks to Dr. Alfred Stansfield, who had so long assisted him in conducting this research, but had now left him in the capacity of assistant for a post of greater activity as assistant professor to himself; and to Mr. Merrett, who had succeeded Dr. Stansfield; and to Mr. Brett, who had succeeded Mr. Merrett.

Mr. E. WINDSOR RICHARDS, Past-President, desired to offer the congratulations of the Members present to Sir William Roberts-Austen upon the honour of knighthood, which had at the beginning of this year been conferred on him by Her Majesty; and to express their hope that he and Lady Roberts-Austen would live long to enjoy this distinction. These researches into the structure and constituents of steel had been undertaken, he had no doubt, with a view to throw more light on a most difficult subject, and at the same time to enable manufacturers to improve the quality of their productions. Considering himself to be what was termed a practical man, he was trying in his own mind to put the substance of the present Report into a form which should be of some use in steel works; but he was greatly troubled with so many "ites." Ferrite he could understand, and cementite also he could grasp. Then there was pearlite, which was said to resemble mother of pearl; and this he could picture fairly well in his mind. But what was meant by Martensite, and by Sorbite? by Troostite? and lastly by Austenite? It seemed to him that the magnified sections of steel illustrating the Report represented only a tiny spot of the steel. Interesting and beautiful as the

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(Mr. E. Windsor Richards.)

sections were, yet looking at that of Austenite and Martensite, shown in Fig. 22, Plate 7, it was rather difficult he thought to distinguish one substance from the other with the naked eye; and when it was considered that it was here magnified 850 times, it seemed to him it was such a small speck of the whole piece of steel that he was not able to believe it was a fair representation of the quality of the steel. Even if the piece of steel operated upon were only about half an inch square, Fig. 22 ought to be about 35 feet square in order that it might represent the whole of so small an area. Then an opinion could be formed as to what quantity of Austenite and Martensite there was in the area of half an inch square. It surely could not be that the piece of steel was all Austenite and Martensite: there must be other constituents in it. Again, supposing a succession of thin slices, say only 1–100th of an inch thick, were taken off the section, would there still be the same arrangement and proportion of Austenite and Martensite in each slice? and so on throughout the whole length of the bar?* Steel bars were now rolled in England as much as 300 feet long. Looking at Figs. 21 and 22, was it to be understood that the whole length of a bar, weighing something like a ton and a half, rolled from an ingot containing 1·8 per cent. of carbon, would be all Austenite and Martensite?

Sir WILLIAM ROBERTS-AUSTEN said yes, if it had received the same thermal treatment throughout its entire length.

Mr. WINDSOR RICHARDS asked at what period of its manufacture? when it first came out of the heating furnace? or when it was finished?

Sir WILLIAM ROBERTS-AUSTEN said Martensite and Austenite were both constituents of hardened steel. The metal would have to be quenched in order to produce them.

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* At the time this question was asked, the information contained in page 63 had not been supplied.

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Mr. WINDSOR RICHARDS was much puzzled to know whether all these ingredients of steel were metalloids, or earthy matters, or occluded gases seeking liberation, or cleavages of crystals. The late Mr. Daniel Adamson he remembered a good many years ago speaking highly of steel as a homogeneous soft metal, and comparing it with that "dirty nasty stuff" iron, which he called "concrete." Some of the sections shown in Plates 6 to 15 certainly bore a striking resemblance to concrete. For many years past the belief had been entertained that the steel now made was a remarkably homogeneous metal; and now it seemed as though an attempt were being made to undermine this belief, and to make out that the whole of such a bar of steel as he had described was of the nature of concrete. Before many more of these "ites" were discovered, would it be possible to arrange a nomenclature which would be more easily comprehended by ordinary minds? The present names appeared to him to be given empirically by godfathers self-ordained. The photographs shown by Sir William Roberts-Austen were most interesting; the amount of time and labour that he had given to this study must have been prodigious; and he deserved the warmest thanks of the Institution for all that he had done.

The PRESIDENT thought the illustrations exhibited by Sir William Roberts-Austen had been considered by the members present to be the most attractive part of the proceedings. Whatever might be said about the "ites," it appeared to him that the great varieties of structure shown by the illustrations must mean something, even though it was not yet known fully what they did mean.

Mr. WINDSOR RICHARDS said he was asking only for a better definition of the several new ingredients.

Mr. J. E. STEAD considered the beautiful pyrometrical improvement which Sir William Roberts-Austen had made since his last Report was likely to be of great service in studying the thermal changes taking place in alloys. Also he must congratulate him upon having discovered some new halting points in the cooling curve

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(Mr. J. E. Stead.)

of electro-iron. Although it could not be seen at present that these new halting points were of any practical value, still it was quite possible that they would be found to have some important bearing upon the metallurgy of steel. One question which arose was, whether it might not be really the fact that the hydrogen blown through the Bessemer converter in the moisture contained in the blast was in some way responsible for the somewhat variable results obtained by the Bessemer process, in comparison with those from the open-hearth process. He was glad that this matter was being studied by Sir William, and hoped that in his next report, or on some other future occasion, he would give the Institution the benefit of his further researches. A point of great interest in Plate 2 was that the remarkable halt Ar 3 was coincident with the breaking up of the structure of coarse-grained steels when they were heated up to this temperature: that is, if soft iron—not steel, but practically a carbonless iron, highly brittle owing to its large crystalline structure —was heated steadily up through the successive halting points Ar 1, Ar 2, and Ar 3, the change or breaking up of the coarse structure took place instantly on reaching the point Ar 3, where the great evolution of heat was noticed in cooling down. This coincidence was most interesting indeed, and showed that there was some wonderful internal change taking place in the heated metal. It was indicated not only by a thermal change, but also by a structural change; and it seemed to him that here was pretty strong evidence, or corroborative evidence, of the existence of allotropic change at the point Ar 3. The thirteen illustrations shown in Plates 21 to 23 bore more directly upon the practical side of this subject.

The statement of the late Mr. Daniel Adamson that iron was a "concrete" mass had been quoted by Mr. Richards; and the diagram, Fig. 109, Plate 23, showed pretty clearly what steel containing various percentages of carbon was really composed of when cooled rapidly. The diagram was divided into squares, representing the percentage of carbon along the horizontal lines, and on the vertical lines the percentage of the constituent compounds it formed with the iron. When there was no carbon at all, the whole height of the diagram up to 100 represented the iron: that is, there was 100 per cent. of

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ferrite, or iron free from carbon. But when there was 0·9 per cent. of carbon, there was no free iron as massive ferrite, but there was 100 per cent. of pearlite. The pearlite structure was shown by the shaded area. The composition of the pearlite or eutectic of iron was 86·65 per cent. of pure iron or ferrite Fe, and 13·35 per cent. of carbide of iron or cementite Fe_3C. Immediately that the carbon was increased above 0·9 per cent., free massive cementite or carbide of iron Fe_3C began to appear, containing 93·33 per cent. of pure iron and 6·67 per cent. of carbon. For any percentage of carbon it could be seen from the diagram what proportion of ferrite, pearlite, and cementite was present in the mass. Taking, for instance, about 0·5 per cent. of carbon, and running vertically up the corresponding ordinate, a steel would be found containing about 45 per cent. of ferrite and about 55 per cent. of pearlite. The pearlite structure, or the eutectic of iron, he believed had been called by Professor Arnold true steel; it was the most homogeneous of all the steels. If there was less than 0·9 per cent. of carbon, free iron or ferrite existed; if there was more than this percentage of carbon, free cementite, a hard substance, existed from the point P. Iron might be made to combine with as much as 4·8 per cent. of carbon; but even with this maximum amount of combined carbon there was still a certain proportion of the pearlite structure accompanying the mass of cementite, as seen in the diagram, Fig. 109, Plate 23.

In page 54 Sir William Roberts-Austen had referred to certain results which he had himself communicated to him, as to the small amount of carbon that would separate in the free state from iron containing 0·04 per cent. of carbon. Fig. 96, Plate 21, was a section, magnified 50 diameters, of a highly brittle annealed piece of soft Swedish steel containing 0·04 per cent. of carbon, showing the free cementite in small white patches. It was not pearlite in this instance, and that was the peculiarity. The ground mass of the section was ferrite. On breaking this steel, fractures passed through the ferrite, and not through the brittle cementite. It had been said by Sir William Roberts-Austen (page 54) that it was a rare occurrence to have a mass of cementite in soft steel; but

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(Mr. J. E. Stead.)

he thought exception must be taken to that statement, because, although it was a rare occurrence to have it in massive pieces of soft iron, yet thousands of tons of the thin soft-iron sheets which were annually made into plates and galvanized, and sent out of this country to all parts of the world, had practically all got carbon massed together in them in the state of cementite. The peculiarity about the massive pieces of soft steel was that, although they were annealed in the same way as the thinner sheets, yet as a rule the annealing did not cause the segregation of cementite.

In Fig. 97, Plate 21, was shown a structure of a piece of soft steel containing 0·15 per cent. of carbon, magnified 50 diameters, which was developed by heating to whiteness, about 1,300° C. or 2,370° F., and then quenching it in water. This showed the Martensite structure in soft steel. The carbide appeared to diffuse itself throughout the whole area of the section; and when etched with nitric acid diluted with five times its weight of water, the structure looked as if it had been brushed over right and left with dark coloured paint, but always in straight lines, never in curves. This was the peculiarity of Martensite structure. There was a marvellous difference between this and the same steel unquenched.

In Fig. 98, Plate 21, was represented a polished and etched section of steel containing about 0·27 per cent. of carbon, magnified 200 diameters. It had been slowly cooled by placing it in the centre of a large mass of molten blast-furnace slag and allowing it to cool down with this; the time taken to cool from about 1,300° C. or 2,370° F. down to 15° C. or 60° F. was more than 48 hours. The structure of this steel differed from that of any of those shown by Sir William Roberts-Austen, inasmuch as the pearlite areas were here surrounded with massive envelopes of cementite. This was evidence that, on very slowly cooling steels containing little carbon, say from 0·1 to 0·4 per cent., the fine laminæ of the cementite in the pearlite tended to fall together or coalesce, and form massive cementite bands; and that probably, if the cooling was sufficiently slow, the pearlite would be entirely replaced by an equivalent quantity of massive cementite. On heating this sample to just above 700° C. or 1,300° F., and then quenching it in water, the

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pearlite areas were converted into Martensite areas of hard steel, and on polishing stood out in bold relief above the surface of the polished section.

Fig. 99, Plate 21, exhibited the structure of tool steel containing 1·38 per cent. of carbon, magnified 30 diameters, which had been heated up to about 1,300° C. or 2,370° F. inside a molten slag ball, and annealed by being left to cool down inside the ball.

The microscope revealed certain structures, and what mechanical engineers required to know was what was the weakest part. It would naturally be expected that the hard brittle carbide or cementite would be the part most fragile and easily broken; and on placing the specimen upon a little hollow dished-out block of metal, and applying a blow on the back of it with a hammer, it was found that a fracture occurred along the weakest lines. If the blow was not too violent, so as not to fracture it completely, the specimen could be removed back to the microscope, and it could be ascertained exactly where the fracture had traversed it. In this way it was possible to determine precisely what part of the structure was the weakest. In the specimen of soft annealed steel shown in Fig. 96, which contained very little carbide, the fracture passed right through the middle of the grains, following the cleavage planes of the crystalline grains. In the specimen shown in Fig. 99 the fracture, instead of passing through the grains, passed along the lines of the white cementite meshes surrounding the dark pearlite grains.

The scoriaceous areas in steel were a most important subject. It was Professor Arnold of Sheffield who first discovered some time ago that, in small castings of steel containing sulphur, the sulphur or sulphides were thrown to the sides of the crystalline grains, and formed envelopes of a highly brittle character. Such a casting, built up of crystalline grains so enveloped, was exceedingly brittle. A specimen of this kind was shown in Fig. 100, Plate 21; the grains of steel were here meshed round with sulphide of manganese. In this particular character of brittle steel Professor Arnold had found that, after it had been heated up to a certain temperature, the scoriaceous sulphide areas segregated into globules, and the steel lost all of its brittle character. If the casting was large

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(Mr. J. E. Stead.)

enough, he had himself found that the heat in the mass was sufficiently great to cause this segregation or balling up of the sulphide. The weakness caused by the meshing of sulphides was not likely therefore to occur in a large casting when sulphur was present, but in small castings only.

In Fig. 101, Plate 21, magnified 130 times, was shown a structure of a steel rail head, such as had not been shown by Sir William Roberts-Austen. Here the peculiarity was that the rail head had broken away or laminated badly on one side: a peculiarity which was coincident with the dark pearlite and light ferrite areas being here arranged in parallel seams. Had the two, as was usual, been intimately mixed up together, he anticipated that the lamination would not have occurred. The lenticular slag-areas of intermediate tint in Figs. 101 and 102, were sulphide areas, and consisted in these instances of sulphide of manganese. They originally existed in the ingot as microscopic globules; but on rolling the ingots they became elongated, and assumed a more or less cigar-shaped form. In Fig. 103, Plate 22, was shown a section of the same steel after crushing; the scoriaceous areas had here been narrowed and lengthened, like the ferrite and pearlite in which they were interspersed. To these sulphide or scoriaceous areas in steel rails attention had been directed by certain investigators, who had assumed, perhaps prematurely, that the scoria was responsible in a great measure for the deterioration of the steel rails, axles, shafts, &c. If scoria had such an evil effect in steel, how much greater effect should be produced by the larger quantity of it in wrought-iron; for as a rule ten times as much scoria would be found in the piled wrought-iron as in the steel.

In Fig. 104, Plate 22, was shown a longitudinal section of good wrought-iron, magnified 50 diameters; the iron was represented by the light part, and the dark part represented the cinder or scoriaceous matter. The bar of iron, from which this section was obtained, was about $\frac{3}{4}$ inch diameter, and was actually tied when cold into a knot, and bore almost any amount of severe treatment without breaking. In spite therefore of all these large masses of scoriaceous matter in the iron, it was of excellent quality; and as this much larger quantity of

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scoria, always present in good iron, did not of itself cause it to be easily fractured, it appeared to be premature to assume that a fraction of this amount would be dangerous in steel. In studying microstructures the greatest care he thought was needed before drawing practical conclusions. The sulphide areas or masses, in the most sulphurous steel that he had ever examined, he estimated at not more than a half of one per cent. The best iron shafts of steamers and axles of wagons, etc., contained from 1 to 2 per cent. of scoriaceous matter.

As supplementing Sir William Roberts-Austen's sections illustrating the structure of the heads of rails, Fig. 105, Plate 22, showed a portion of the surface, natural size, of the head of the steel rail which had caused the accident at St. Neot's on the Great Northern Railway (10 November 1895). The trains travelled from left to right, and the steel flowed in the same direction. With regard to the transverse curved cracks in this rail, and in some of thirty or forty other rails which he had examined, his experience had shown clearly that they did not develop, unless the rail head became greatly worn down and flat at the crown. When the rail head had become so much worn, there were two reasons why the cracks should then develop. The first was that, when the rail became so flat, there was little side flow of the material; the flow was mainly in the longitudinal direction, and the steel could not travel along the whole length of the rail and go off at the far end. Instead of doing so, the particles behind were forced or crushed forward over the particles in front. The longitudinal vertical section of the St. Neot's rail head in Fig. 106, magnified 10 diameters, which had been polished and etched with nitric acid and then re-polished, showed that the top part had been travelling in the direction in which the trains passed over it. It also showed the hammer-hardened skin of the upper surface, with the curved transverse cracks through it, and the porosities or minute cavities that had originally contained sulphide of manganese, which however had been removed by the etching liquid. These latter illustrated Sir William Roberts-Austen's remarks on molecular porosity in a former Report (Proceedings 1893, pages 106–7).

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(Mr. J. E. Stead.)

In Fig. 107, Plate 22, was shown, not a rail head, but the surface of a worn locomotive tire, magnified 50 diameters, showing how the steel was crushed and tended to flow round the circumference. Fracture was easily effected along the lines from left to right. The same cracks were liable to occur in a locomotive steel tire as in a steel rail. Although they were scarcely visible, yet on taking a thin transverse section from the surface, and testing it by bending it in the way he had already described, with the worn surface downwards, the bending invariably formed the same kind of curved cracks that were seen in Fig. 106 in the surface of the St. Neot's rail head. He had been informed by a competent authority that cracks apparently did not grow in locomotive steel tires as they did in steel rails. So far as his own experience went, the cracks never penetrated to any great depth in a tire, but were only superficial. This pointed to the conclusion that, as there was no possibility of flexure in the tire, because it was perfectly rigid on the wheel, the cracks were developed first of all by the flowing of the steel over itself, and did not gradually increase in depth, as they did in steel rails, which were not supported so rigidly.

The second cause for the development of cracks was apparently to his mind the comparatively coarse crystalline structure of the interior part of the rail head. It had been shown clearly by Mr. A. Sauveur,* whose work had been fully confirmed by himself, that in the exterior portion of a rail, and in the upper surface of a new rail head, the structure was of a much finer grain than in the interior. It was well known that a coarse grained steel was much more liable to fracture than one of fine grain. It appeared to him probable therefore that a second cause for the development of cracks in the rail head and in the tire might be the large size of the crystalline grains. In all the steel rails that he had examined which showed a development of cracks, the cracks had been found in those portions of the rail heads which were the most coarsely granular. Even if this was regarded as only

* American Institute of Mining Engineers, Chicago Meeting, 1893; and Cleveland Institution of Engineers, 14 November 1898, pages 26–8.

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a coincidence, still it pointed in the direction of having for rails and tires steel of fine grain throughout the whole mass. How was this to be obtained? In his present Report (page 64) Sir William Roberts-Austen had referred to the fact that, if steel was rolled at a comparatively low temperature, finer grain was obtained; and had said that, the higher the temperature at which it was rolled, the coarser was the grain. It was hardly possible he feared that steel manufacturers could be expected to work with any more scientific accuracy than they did at the present time in making steel rails; they were doing their best, and it seemed hardly likely they could be induced to employ the highly sensitive pyrometer described in these Reports, and by means of its records to obtain the exact temperature which would give the best structure to the steel. Therefore he was inclined to believe that the best practical way to treat the steel, after it had partially cooled down, was by simply heating it up to a temperature at which the carbon diffused out of the pearlite into the ferrite: a condition of things that was invariably accompanied by a breaking up of the structure. According to the researches of Brinell,* steel after it had cooled down to a certain critical point, no matter how coarse might be its grain, was invariably broken up into a fine structure on reheating to a certain critical point between 700° and 850° C. or 1,300° and 1,550° F. This he had himself confirmed as an undoubted fact; in experimenting upon pieces of rails he had found it was quite easy to obtain throughout the whole section a beautifully fine structure; and it seemed to him that this was what really should be aimed at. Whether the manufacturers and the users of steel rails would feel inclined to pay the extra 1*s.* or 1*s.* 6*d.* a ton, which would be necessary in order to get this finer structure for their rails, he could not say; but he thought the trial was well worth making.

As already mentioned in page 76, it had been stated by certain investigators that the sulphur flaws which were represented in Figs. 101 and 102, Plates 21 and 22, had a tendency in steel rails to cause the material to develop fractures under fatigue or work. But in Figs. 102

* "Metallurgy of Steel"; by Professor Henry M. Howe. New York, 1890.

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(Mr. J. E. Stead.)

and 103, Plate 22, were shown specimens of really excellent steel, having a large elongation and a high tenacity; it was from a tail shaft of a screw propeller. On micro-mechanically testing it in the manner already described, he had found after crushing it that the fracture did not traverse through the scoriaceous areas, one of which was shown at S, Fig. 103, but along the borders of the pearlite areas, missing the scoriaceous areas altogether. It appeared to him therefore that the weakness was here due to the laminæ of the pearlite being pressed together into horizontal layers, and that fracture passed between these flattened plates, and that the scoria was not responsible for the weakness.

In Fig. 108, Plate 23, was shown a section of annealed soft steel containing 0·12 per cent. of carbon, which illustrated the wonderful effect of treatment by heat. By annealing at a low temperature it had been crystallized in coarse grains, as seen in the left-hand half of Fig. 108. On heating it up to just above the critical point Ar 3, about 900° C. or 1,650° F., and then quenching it in water, it was found that the whole of the coarse structure had disappeared, and the beautiful fine-grained structure seen in the right-hand half of Fig. 108 had been developed. This specimen therefore afforded another illustration of the fact that the abrupt and enormous absorption of heat at Ar 3, in heating up steel with little carbon in it, was exactly coincident with the breaking up of the crystalline structure.

Professor J. O. ARNOLD had read the present Report with much interest and gratification. In connection with the first and second Reports (Proceedings 1891, page 587, and 1893, page 154–5) he had strongly suggested the necessity of correlating the results obtained by the Alloys Research Committee with those arrived at by the microscopic examination of the structures; and also that hydrogen might possibly be the cause of the point of recalescence Ar 3 in the cooling curve (1893, page 158). At that time it had seemed to him that Sir William Roberts-Austen was not inclined to attach much value to those suggestions; and therefore he was greatly pleased to find that the present Report was largely taken up with micro-sections

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and with a description of the newly discovered recalescent point of hydrogen. He joined with Mr. Stead sincerely in congratulating Sir William on the really beautiful arrangement of the pyrometer for registering small evolutions of heat; it must indeed, as Mr. Stead had remarked (page 71), be of great value. With reference to the evolution of heat at 487° C. or 908° F., Mr. Stead had observed (page 72) that it was not quite evident at present what the practical interpretation of this point should be. He should therefore like to suggest for consideration that, in boiler-plate steel and ship-plate steel, there was often found a critical mechanical point at what was called a black heat. If the boiler plates or the ship plates were worked at that heat, as in bending operations, they assumed an extraordinary brittleness. The point at which their brittleness came on seemed to him to be just about the temperature of the hydrogen evolution; and it would be a good thing if the two occurrences could be associated with each other, and if it could be definitely shown that the brittleness encountered in working steel at a black heat was due in some degree to hydrogen between the crystals.

As an analogue for steel, frozen brine had been selected by Sir William Roberts-Austen; and while some might naturally be inclined to take such an analogue a little coldly and with a grain of salt, it appeared to himself that the comparison was broadly a good one, and would apply well to illustrate the points which Sir William desired to bring out. One question which he should like to ask was, whether the two terms eutectic and cryo-hydrate were meant to be synonymous. If the term eutectic referred to the solid whilst still in solution, which in the frozen brine was the cryo-hydrate, and which in the steel would correspond with what might be called the cryo-carbide at 0·9 per cent. of carbon, then they seemed to be synonymous. But was it admitted that the cryo-hydrate in the liquid brine was certainly a eutectic mixture without any combination? If, as the use of the name cryo-hydrate might seem to imply, it was understood to be a genuine chemical combination in solution, but a decomposed mixture when solid, then he accepted the analogue altogether.

With reference to the carbon-solution curves in the diagram, Plate 5, direct measurements of the diffusion of carbon and of twelve other

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(Professor J. O. Arnold.)

elements through hot iron had been made during the past two years at University College, Sheffield; and the data there obtained did not exactly agree with some of those contained in this Report. It seemed to be thought that carbon—or, as he should himself prefer to call it, carbide—was insoluble in what was called β iron. Referring to Plate 5, the range of β iron lay between the two points of recalescence Ar 2 and Ar 3; and if he rightly understood the Report, it was considered that carbon would not diffuse within that range of temperature, and that the iron must pass above the higher point Ar 3 before diffusion could begin to take place. The results however of the direct measurements made at Sheffield were that the diffusion did really commence just above Ar 2, at which temperature the carbon began to diffuse into the iron, and a diffusion diagram was obtained something like that shown in Fig. 110, Plate 23, in which the temperature was measured vertically and the percentage of carbon horizontally. It was found that the carbon, in the form of carbide of iron, was insoluble in the iron up the line AB until the point Ar 2 was touched at about 760° C. or 1,400° F. At about this temperature, given a sufficient time and an excess of carbide, the iron could be saturated along the horizontal line BD up to 0·9 per cent. of carbon, or the cryo-carbide point of carbon. After this, on further raising the temperature with an excess of carbide still present, there was a gap DE of at least 150° C. or 270° F., possibly of 200° C. or 360° F., where the percentage of carbon remained stationary, so that the line DE was vertical; and it was only when the temperature reached from 900° to 950° C., or 1,650° to 1,740° F., that the diffusion went on again along the horizontal line EG, and the steel could be fed up to 2 per cent. of carbon.

The true meaning involved in the terms used in the Report—α iron, β iron, and γ iron—resolved itself largely he thought into a question of definition. The definition of allotropy employed originally and up till ten years ago had clearly implied a chemical allotropy. The latest definition given by Sir William Roberts-Austen of the phenomenon of allotropy, and now confirmed by him, was that it was a change in the internal energy of a mass at a critical temperature,

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unaccompanied by any change of state. If this was accepted as a definition of allotropy, then undoubtedly the diagram Fig. 110 pointed to allotropic iron; and he was himself fully prepared to accept the definition, provided it was fully applied, because then it would mean, he thought, that water between 4° and 0° C., or 39° and 32° F., during the time it was expanding and before it formed ice, was an allotropic modification of water. This however would be a new definition, he thought, so far as standard works on chemistry were concerned; but if it were accepted, he was fully prepared to admit that the changes in iron were allotropic, though on the original chemical definition he could not admit it.

There was one analogy in the Report (page 50) which he could not quite follow: namely the separation of carbon from iron as a carbide or well marked binary compound Fe_3C, and the separation of copper sulphate Cu SO_4 from its solution as Cu $SO_4 + 5H_2O$. Here the copper sulphate represented the carbide, and the water represented the iron. Now the solution of sulphate of copper, which was blue vitriol, would be somewhat difficult to assimilate physically; and he found the same difficulty metaphorically with the analogy.

The series of steels which he had himself studied at Sheffield had been referred to in page 52 as being in their normal state, when in the condition in which they came from the rolls. This however was a misapprehension; for the steel as it came from the rolls might be in an abnormal state, owing to the difficulties in the finishing temperature; and therefore to make the bars normal they were all carefully heated up to 1,000° C. or 1,850° F., and allowed to cool in air, so as to set them all through in the same thermal state.

The results given by Professor Howe, referred to in page 52, he thought might now be regarded as obsolete. The mechanical influence of carbon on steel was known, or at least the hallucination prevailed in Sheffield that it was now understood; and Professor Howe's results did not agree with many which he had himself obtained. The maximum stress recorded in Professor Howe's figures was about 48 tons per square inch, and the greatest elongation recorded was 38 per cent.; whereas in Sheffield 62 tons and 50 per cent. had

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(Professor J. O. Arnold.)

been obtained. Moreover the Sheffield tests had been made over and over again; and the results which he had published in a paper read before the Institution of Civil Engineers on the influence of carbon upon iron (Proceedings vol. cxxiii, 1895, page 127) represented so large a number of tests that he thought they might be considered to represent fairly the mechanical influence of carbon upon the purest commercial iron known. For this reason it seemed to him that Professor Howe's results had now become obsolete. The tensile strength of 62 tons per square inch in steel containing 1·2 per cent. of carbon was the maximum stress he had himself obtained with the purest crucible cast steel, after either annealing or forging.

Some such protest as that made by Mr. Windsor Richards (page 69) was what he had been expecting from practical men for some time; and although he could not himself go so far in depreciating the value of micro-graphic analysis, he nevertheless thought there was some solid ground for complaint. The needless multiplication of allotropic modifications and constituents he thought was becoming too much altogether. It was true that steel was generally admitted to resemble closely a crystallized igneous rock, such as granite, and that therefore, as in mineralogy, its constituents might appropriately have names given to them ending in "ite." Professor Howe he thought had been the first of the self-ordained sponsors contemplated by Mr. Richards; and he had named ferrite, pearlite, and cementite, three well-known constituents discovered by Dr. Sorby; these names he thought were excellent, and they had been generally accepted, and appeared to be approved by Mr. Richards himself. But with regard to Martensite, Troostite, Sorbite, and Austenite, he feared a good deal of confusion already in these early days was creeping into the science of metallurgy through synonyms, which must be a great trouble to students, and upon which the chief authorities were by no means agreed. For instance, that which in page 56 and Fig. 18, Plate 7, was called Troostite, he called Martensite; and what was called Martensite in page 56 and Fig. 6 (page 55) and in Fig. 19, he was unable to understand at all by this designation, and it seemed to him to illustrate a great fault in the

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nomenclature adopted. Martensite had been defined as steel containing from 0·1 to 0·9 per cent. of carbon quenched out; in the cross section therefore of such a bar so treated the whole structure consisted of Martensite throughout. Now the first characteristic property of a mineral constituent was that it should have a fairly definite composition and a fairly definite hardness: in fact the scale of hardness generally employed was based upon certain minerals whose hardness was constant. But if a structure of hardened steel, containing from 0·1 to 0·9 per cent. of carbon, was to be called Martensite, it presented an extraordinary paradox as a mineral constituent. For if a crushing piece of steel, containing 0·1 per cent. of carbon, 0·564 inch diameter and 1 inch high, was hardened and tested by compression, it would crush down into an ordinary cheese-shaped piece, which had undergone perhaps 55 per cent. of compression. But if a steel containing 0·9 per cent. of carbon was treated in the same way, there was absolutely no compression obtained. Again a bar of the steel containing 0·1 per cent. of carbon quenched out could be bent double, twisted, rolled up, and tortured in any other way; it was perfectly tough. But the steel containing 0·9 per cent. of carbon was as brittle as glass. Therefore it seemed to him that, if Martensite and the other terms were to be of any practical use to engineers, they should convey to the mind some idea of the property of the material. The properties of ferrite, of pearlite, and of cementite were known; but Martensite, as defined by M. Osmond, Sir William Roberts-Austen, and Mr. A. Sauveur, seemed to him to cover an indefinite range of properties, and he therefore considered the name altogether inappropriate: in fact, except under certain conditions, he could not recognise it as indicating a distinct constituent. Austenite was obtained by quenching suddenly from a high temperature a steel containing say 1·6 per cent. of carbon. If a razor steel was treated in that way, he was afraid the effect would be disastrous: the property of such a razor would be, in the vernacular of the Sheffield grinders, "it'll oupen an' shoot, but it waint coot."

From a scientific point of view, the question of the properties of iron and steel seemed to him to have been argued in a circle for ten

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(Professor J. O. Arnold.)

years past, and to have come back again almost to the same point. But this having been done, both sides he thought were now practically agreed that their views had been brought to coincide by the evidence adduced on either side. The crucial question was, whether the carbon in hardened steel was in solution as carbon in the free state, or whether it was diffused as a carbide of iron. If it might be present as a carbide—as he thought Sir William Roberts-Austen was willing to admit, and as had already been admitted by M. Osmond and by a long line of metallurgists in England and other countries—then he thought the fifth Report of the Alloys Research Committee might be considered to be particularly valuable as ending a controversy which had been carried on so long.

MR. THOMAS WRIGHTSON joined in the congratulations to Sir William Roberts-Austen upon the great improvement he had made in the recording pyrometer, by duplicating the thermo-junction and also the galvanometer. By these means he was enabled to get on a larger scale the curve representing the thermal changes which he was now investigating. These changes were highly interesting; and engineers might now look forward to the day when a defect produced by such natural change in the material might be neutralised by applying processes during the time it was passing through the change. In Plate 2 were shown three or four remarkable changes. Not being a chemist, he could not discuss the question of allotropy from the chemical point of view; but he thought that Sir William Roberts-Austen was quite right in regarding these changes as a physical allotropy. The changes might indeed be of great importance in future experiments in the process of iron and steel manufacture. It was quite conceivable that iron or steel, before it arrived at one of these critical periods, could be affected by any particular process in quite a different way from that in which it would be affected while passing through that critical period. Sir William he thought had done great service to science in investigating what these changes were, and had dealt with three or four of the most important changes. He should himself like to draw attention to another change at a higher temperature than had been reached in Plate 2. Some years ago he

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had made many experiments upon the remarkable change which occurred in iron at the much higher temperature of from 1,300° to 1,400° C. or 2,370° to 2,550° F.; and between these limits he had found that iron had the remarkable property of reversing the ordinary law of contraction by cooling, and it expanded in cooling during this period. As he had described on a former occasion (Proceedings 1895, pages 283–9), this had been determined with regard to cast-iron by experiments on the flotation of balls of solidified iron in liquid iron. At the time of making those experiments he thought it was likely that this expansion in cooling was connected in some way with the curious property of the regelation of ice. The fact had been mentioned by Professor Arnold (page 83) that between 0° and 4° C. or 32° and 39° F. there was a similar change in water, which in cooling expanded instead of contracting, and thereby caused the remarkable phenomenon of regelation in ice: that is, when two wet surfaces of ice were pressed together, freezing took place. These phenomena were analogous to the welding of iron, and he thought might be intimately connected therewith. The difficulty he had met with in experimenting with wrought-iron by the flotation process was that wrought-iron became so viscous in melting that it was impossible to float solid wrought-iron in liquid wrought-iron, because immediately the ball of solidified wrought-iron was put into the liquid wrought-iron, the liquid wrought-iron became so viscous that the buoyancy of the solidified wrought-iron could not be observed. Sir William Roberts-Austen, with whom he had talked the matter over, had kindly undertaken to join him in investigating it at the Mint. They had abandoned the idea of attempting to float the solidified wrought-iron in the liquid wrought-iron, and had approached the matter from quite a different direction. About fifty years ago Lord Kelvin and his brother, the late Professor James Thomson, had proved, not only mathematically but experimentally, that any substance which reversed the ordinary law, and expanded in cooling, would also cool by pressure; and a series of experiments had been arranged at the Mint by Sir William Roberts-Austen and himself, whereby they could examine the cooling which was produced by compressing

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(Mr. Thomas Wrightson.)

wrought-iron at high temperatures. Rods of wrought-iron were placed in an apparatus somewhat similar to that shown in Fig. 2 (page 38), and were pressed endwise by a hydraulic press, while heated at the same time by a Thomson-Houston electric welding machine (see Proceedings 1895, Plate 44, Fig. 14). As soon as the iron came to the welding temperature, it was shown by a similar apparatus to that sketched in Figs. 1 and 2 (page 38); the thermo-electric junction was passed into the centre of the rod and connected with the galvanometer, and a ray of light from the mirror of the galvanometer was received upon a travelling photographic slide moved by clockwork. A curve was thereby obtained, which showed whether the temperature was rising or falling; and it was found that, when the iron reached a temperature anywhere between 1,300° and 1,420° C. or 2,370° and 2,590° F., any pressure to which it was subjected caused a fall in temperature (Proceedings 1895, Plate 45). This was an important verification, because it also implied, according to the law discovered by Professor James Thomson and elaborated by Lord Kelvin, that within these limits of temperature the iron would also expand in cooling; and therefore this method had enabled that critical period to be examined in a highly satisfactory way.

With regard to the other periods of change in the property of iron as it passed through the different ranges of temperature, he thought it was quite reasonable to suppose that, as in the case of hammering or pressing in welding, processes chemical or physical applied to the iron during these other critical periods might most probably have a permanent influence upon the qualities of the material, which it would be of extreme interest to mechanical engineers to understand. He trusted therefore that Sir William Roberts-Austen would continue these investigations, because he believed investigations of this kind were the foundation of knowledge in this particular branch of science; and he had no doubt that he would thereby succeed in making a much more exact science of a subject which up to the present time had been mainly a matter of rule of thumb.

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Dr. ALFRED STANSFIELD drew attention in the diagram, Plate 5, to the part of the curve SE, beyond the point E, which was shown dotted in the diagram. In the fourth Report (1897, Plate 11) the line SE was left off at about the point E; and the reason of its not being continued further was that the amount of heat given out by the separation of cementite, which produced the points on the curve between S and E, was so small that it was difficult to determine their exact position, especially at the higher temperatures. There were other considerations however which enabled a prolongation of the curve SE to be attempted in a general way. The vertical ordinates of the curve SE, measured from the horizontal line SP, indicated the amount of free cementite in the steel; and therefore, even when the positions of points on the curve could not be proved by the ordinary cooling-curve method, the approximate height at which the curve should be drawn might be found, for high-carbon iron containing more than 1½ per cent. of carbon, by simply estimating under a microscope, or ascertaining by chemical analysis, the amount of free cementite that was present. The curves in Plate 5 represented samples of fairly pure carbon pig-iron—not white or manganese pig-iron—which had been cooled slowly from temperatures above their melting point. Under these conditions it was known that the amount of cementite decreased with the increase of total carbon in the iron beyond a certain amount of carbon; and consequently somewhere beyond the point E the curve should turn down. It might even be possible to reach a percentage of carbon K, say perhaps about 4·2 per cent., at which the cementite ceased to be present at all, and free ferrite came in, as indicated by the ascending dotted curve KL.

The interesting example of diffusion, given by Professor Arnold in Fig. 110, Plate 23, was in no way at variance with the views put forward in the present Report, and was easily explained by means of Plate 5. If anything, 750° C. or 1,380° F. was rather below the temperature of the critical point Ar 2, as measured and indicated on the diagram, Plate 2; and all that could be said definitely, because there was always some amount of uncertainty in making experiments of this kind, was that this temperature was above the lower critical

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(Dr. Alfred Stansfield.)

point Ar 1. For the present purpose this was all that was required; because when iron containing a certain amount of carbon was heated above Ar 1, which was a point occurring between 650° and 700° C. or 1,200° and 1,290° F., a certain amount of the iron went into solid solution with the carbon, and even at the temperature 690° C. or 1,270° F. became changed from α or soft iron, not merely into β or hard iron, but some of it into γ or plastic iron: so that at any temperature above 690° C. or 1,270° F. there was a certain amount of γ iron present, the amount of which depended simply on the percentage of carbon; and consequently there was free diffusion of the carbon in the iron up to an amount of 0·9 per cent. of carbon. The diagram of Professor Arnold's, Fig. 110, Plate 23, represented what might be called a solubility curve of carbon in iron, the vertical ordinates giving the temperature, and the horizontal abscissæ indicating the solubility of the carbon in the iron. Up to 700° C. or 1,290° F., or, as measured by Professor Arnold, up to 750° C. or 1,380° F., there was practically no carbon dissolving in the iron. About 700° or 750° C. (1,290° or 1,380° F.) the carbon dissolved to the extent of 0·9 per cent. Then the carbon did not increase much with a considerable rise of temperature, up to about 900° C. or 1,650° F.; and then it increased considerably at about this temperature. This was roughly what was seen from the curve in Plate 5. The horizontal line SP, which indicated the Ar 1 change, though perhaps not really extending quite so far to the left as to reach the zero ordinate denoting pure iron or ferrite, nevertheless came so close to it that its extremity P should be somewhere between 0·00 and 0·07 per cent. of carbon; because the critical point Ar 1 at 690° C. or 1,270° F. occurred in the cooling of iron containing 0·07 per cent. of carbon, but did not occur in the cooling of electro-iron. From this it followed that carbon was practically insoluble in iron at temperatures below 690° C. or 1,270° F. The solubility of the carbon in the iron at the temperature of 690° C. or 1,270° F. was indicated by the length of the line PS, and was about 0·8 or 0·9 per cent. of carbon. There was some uncertainty as to the exact position of the point S, as could be readily understood from the fact that the evolutions of heat along the lines OS and SE were too small

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to allow of determining with exactness the point S at which they met. Moreover there was some difference in the position of the point, depending on the purity of the steel, that is, its freedom from other constituents, such as manganese.

Professor ARNOLD asked whether the solubility of carbon in iron involved the assumption that the carbon was present in the free state, or diffused through the iron as a carbide of iron.

Dr. STANSFIELD replied that no assumption was made as to this question; it was left open to be taken either way. From the point S in Plate 5 it would be noticed that the solubility of the cementite in steel progressed along the line SE; as the temperature rose it increased slowly, until at about 900° C. or 1,650° F. it increased more rapidly. This portion of Plate 5 might thus be considered to correspond roughly with Professor Arnold's Fig. 110, Plate 23; and he hoped therefore it would be sufficiently obvious that the latter was not in any way a contradiction of the views put forward in the Report. It had also been explained in the Report (page 50) that, when steel containing say 0·2 per cent. of carbon cooled down, although most of the iron, when it crossed the line GO, underwent a change from the γ or plastic state to the β or hard state, and subsequently from the β to the α or soft state, yet some of it remained in solid solution with the carbon, and continued in the γ or plastic state until it reached the line PS; and then parted with its carbon, and changed suddenly from the γ or plastic to the α or soft state.

Mr. ROBERT A. HADFIELD wrote that he heartily congratulated Sir William Roberts-Austen upon this fifth Report to the Alloys Research Committee, and could readily understand how great must have been the tax upon his time in carrying out the large number of experiments now described.

It was highly satisfactory to note in page 42 the admission that pure electrolytic iron did not possess adamantine hardness, and that any modification of the ordinary known physical properties of soft

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(Mr. Robert A. Hadfield.)

iron was due to the presence of other elements, of which one was hydrogen. Having had several opportunities of examining probably the purest iron yet known, containing 99·98 per cent. of iron—produced by Dr. Hicks, Principal of University College, Sheffield, and his colleague, Mr. L. T. O'Shea—he had found that, whilst brittle and fairly stiff to the file, this product, after being heated to a low red, became soft and readily bent double, much like a specimen of soft copper. No reversal of its physical properties was then possible; whether quenched from high or low heats, and whether quickly or slowly, it still maintained its softness and ductility.

The statement in page 48, that steel contained more combined carbon than slowly cooled pig-iron, was one which he could not understand. There were several varieties of pig and cast-iron which contained much more combined carbon than steel, even though they were cooled slowly. White pig-iron was an example; and the carbon in white iron containing manganese remained most obstinately combined, even though annealed by the process used when preparing malleable cast-iron. In this latter instance there appeared to be practically no treatment which was capable of breaking down the intimate combination existing between the double carbide of iron and manganese.

As regarded the solution theory, he regretted his inability to accept it in the form in which it was presented in the Report. As Sir William Roberts-Austen had himself pointed out (Proceedings 1897, pages 36 and 70), full evidence was not yet available for substantiating the theory. It seemed desirable therefore to advance slowly enough in this direction, or there might be much to unlearn. It was with much pleasure that he noted Sir William's cordial reference to Professor Arnold's labours. Speaking for himself and for many in Sheffield, he could say that the work of the latter had proved of the greatest practical value.

Mr. C. FREWEN JENKIN had been asked a year or two ago to examine microscopically a sample of burnt steel. It was a billet taken out of a furnace, which, as the steel makers stated, was burnt and was useless. On examination with the microscope he found it

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looked almost exactly the same as Fig. 31, Plate 9, and was very like Fig. 29. It was clear that the percentage of carbon was here much too high. The steel maker had told him that, the steel being burnt, all the carbon would be burnt out; and as it had originally contained about 0·1 per cent. of carbon, he had been greatly puzzled when he found it now had obviously much more than 0·1 per cent. A separate billet was therefore cut in half, one half burnt, and the other half kept as it was; and he then examined the two under the microscope. The burnt half again showed a higher percentage of carbon than the unburnt half, and chemical analysis gave the same result: the carbon had increased in the burnt steel. The conclusion he came to was that in the furnace the iron had taken up carbon by cementation, and that the burnt nature of the steel must be due to the curious form in which the carbon was, which was not normal; and that in this condition the steel was unsuited to the methods of working it, which were adopted of course for the normal condition of carbon in the steel. This idea had been somewhat strengthened when he learnt that it was generally recognised that the percentage of carbon in the billet was usually found to be slightly higher than in the ingot from which the billet had been rolled. This higher percentage might also be due to the increase of carbon by cementation in the furnace. It might be of interest therefore if Sir William Roberts-Austen would give his explanation of these facts; and whether it agreed with his own or not, it might lead to practical use in showing how to treat burnt steel by some process which would bring it back again to its proper condition.

Sir WILLIAM ROBERTS-AUSTEN mentioned that the long cooling curve of electro-iron, shown in Plate 2, was not one absolutely continuous photographic record, but on account of the great length of the curve it had necessarily been taken in three divisions, which were marked "record No. 1–2–3." The rate of advance of the photographic plate was not quite the same in all three records, and that was why they had been distinguished. Practically however it was a continuous curve. In Plates 4 and 5 it should be understood

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(Sir William Roberts-Austen.)
that, wherever dots or marks were seen along a visible or invisible vertical line, a curve had been taken of the nature of that shown in Plate 2. Thus for any particular variety of steel, containing say 1·75 or 1·8 per cent. of carbon, points of recalescence were found at different parts of the curve. The method of manipulation was not quite so easy as might be imagined from merely looking at the diagrams in Plates 2, 4, and 5; and a great many curves might have to be taken before one was obtained which was successful in all the points of recalescence. In justice therefore to the assistants who had so patiently and perseveringly carried out this work, it was only fair to point out that the work embodied in Plates 4 and 5 was really prodigious, because every vertical line along which dots or marks were seen meant that often six curves like that shown in Plate 2 had had to be taken, before one was obtained which was entirely successful.

In answer to Mr. Windsor Richards' question (page 70) as to whether different parts of a mass of steel showed the same microstructure, he appealed to Plate 17, in which Figs. 76 and 78 were two photo-micrographs prepared from sections cut from the interior of the head and of the lower flange respectively, at the crop end of a rail. Figs. 77 and 79 showed metal cut from corresponding positions, as regarded the transverse section of the rail, but from a part ten feet nearer the centre of its length. It would be seen that, although the grain in the crop end was smaller than that ten feet nearer the centre of the rail, the general structure nevertheless corresponded closely; the constituents were the same, and their distribution was the same, though the samples were taken from places ten feet apart. The comparative smallness of the grain in the crop end was due to its being more rapidly cooled than the other parts in the length of the rail.

With regard to the confusing number of constituents to be remembered (page 69), in slowly cooled steel there were practically only two "ites," ferrite and pearlite; while quenched steel gave one other, Martensite. With singularly little trouble the appearance of these could easily be mastered; and when once this was done, their presence could always be detected in any section.

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The segregation of cementite mentioned by Mr. Stead (page 73–4) probably took place in all steels which were comparatively low in carbon: that is, steels in which the carbon was less than 0·5 per cent. In armour-plate and rail steel, which had been annealed for some time at a temperature of about 600° to 700° C. or 1,110° to 1,290° F., the carbide invariably appeared to be drawn together into more or less homogeneous patches, as seen in Fig. 81, Plate 18. Minute laminæ of carbide moreover generally appeared, disseminated throughout the mass. It was possible that in the thin sheets mentioned by Mr. Stead minute laminæ of Fe_3C were dissociated and the carbon oxidized, so that the finished plate consisted merely of a matrix of ferrite crystals containing little knots of cementite.

Rails with a large grain, he agreed with Mr. Stead (page 78), were much more liable to fracture than those having a small grain. In most rails, especially those low in carbon, the grain was smaller and the ratio of the ferrite to the pearlite much greater on the outer parts of the rail than in the interior. In the unworn external parts of the St. Neot's rail (page 77) the grain was small, and the ferrite considerably in excess of that in the interior. The presence of much manganese almost invariably caused the grain of a rail to be large; and it was well known that rails containing too much manganese were not trustworthy.

In answer to Professor Arnold's question whether the terms eutectic and cryo-hydrate meant the same thing (page 81), they might be regarded as synonymous if it were remembered that the term cryo-hydrate was now held to be inaccurate, as suggesting chemical combination. It was now admitted that the cryo-hydrate in the liquid brine (page 45) was certainly a eutectic mixture without any true combination. The word cryo-hydrate had been employed by Guthrie before this was known; it would be better to reject it in favour of the word eutectic. The eutectic of an alloy however was the same thing as the so-called cryo-hydrate of a saline solution.

As regarded the tenacity curves of carburized iron (page 83), the fact of importance was the maximum strength occurred at the saturation point of carbon, that is, with about 0·9 per cent. of

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(Sir William Roberts-Austen.)

carbon. On the exact degree of strength which could be obtained in carburized iron by the most approved methods of treatment, he was not careful to insist.

The terms Martensite, Austenite, Troostite, and Sorbite had on various occasions been explained* by Osmond, who had justified the existence of the constituents they represented.

As regarded diffusion of carbon in iron, it had been shown by Dr. Stansfield (page 89) that there need be no divergence of view. Professor Arnold's diagram shown in Fig. 110, Plate 23, was practically one of solubility of carbon in iron, and as such practically agreed with the curve shown in Plate 5. It was not yet known whether the carbon diffused as carbide, or as dissolved carbon, that is, as a solution of graphite in iron. Neither was it known how the carbon was dissolved. It should moreover be remembered that the solution of carbon in iron might under certain circumstances deposit the carbon either as graphite or as cementite. There was no evidence whatever of the existence of the hypothetical compound $Fe_{24}C$, which was simply the saturation point of iron by 0·89 per cent. of carbon, expressed as a compound; whereas it was really a eutectic without any molecular composition.

The views so long held by M. Osmond and himself as to the allotropy of iron he was glad to find were now widely accepted. Both of them anticipated that the new method of recording and obtaining the cooling curves would in the future be highly useful, especially in relation to the new hydrogen points of recalescence.

Electro-iron was not always of adamantine hardness, he agreed with Mr. Hadfield (page 91); but sometimes it was. If it was soft, this was merely because it had been deposited with an electric current of a particular current-density, and had come down in a state of fine segregation.

Mr. Jenkin's question as to means of restoring burnt steel to its normal condition (page 93) demanded further experiments before a complete answer could be given. Burning did not always mean removal of carbon, but was often due to change of structure arising from the temperature to which the metal had been raised.

* Roberts-Austen, "Introduction to the Study of Metallurgy," 1898.

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In conclusion, he desired to thank the members for the warm reception they had given to the present Report. With regard to the written contributions to the discussion, he cordially thanked Professors Callendar, Ewing, and Ledebur, for their interesting and appreciative communications.

The PRESIDENT had much pleasure in informing the meeting that, in connection with the knighthood which had just been conferred by the Queen on the author of the Report, there was reason to believe that this honour had been "given for science"; Lord Salisbury it was hoped had himself seen the previous Reports of the Alloys Research Committee. The Members he was sure would all wish to join him in expressing the thanks of the Institution to Sir William for such a highly interesting and valuable piece of work as the present Report. The research work of the Institution had always been a special feature, ever since it was first entered upon. The Annual Report of the Council for the past year gave a summary of the various directions in which at the present time research work was proceeding; and the work of the Alloys Research Committee, which was conducted so ably by Sir William Roberts-Austen, was certainly not one of the least important of this valuable series of researches. The Council had yesterday had under consideration the question of the continuance of this Alloys Research; and had decided that the great value and promise of the results already obtained fully justified them in placing in the hands of the Alloys Research Committee and of its able experimentalist and investigator, Sir William Roberts-Austen, the means of proceeding yet further, in order to discover as much as possible of the interior structure of iron and steel. They were fully sensible of the great indebtedness the Institution was under to Sir William Roberts-Austen for so valuable a piece of work as the present Report, following upon the four others which he had previously prepared for the Institution. Not merely had this fifth Report conveyed to the Members so much information from his own work, but it had also been the means of bringing into the discussion much that had been interesting from other authorities, whom they were always glad to see present and to

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(The President.)

listen to. Of these he might add that Mr. Stead had considerably abridged his remarks; and the Institution would therefore be happy to receive from him a still fuller exposition of his views, in the form of a separate paper as soon as he could prepare it.

Professor A. LEDEBUR, Freiberg, Saxony, wrote that he had read with great pleasure Sir William Roberts-Austen's present Report, and considered the results recorded therein denoted a fresh important advance in the knowledge of the subject under investigation. It had all along been his own conviction, which he had several times expressed, that the nature of alloys, and particularly of the iron-carbon alloys, would be better understood if they were considered as solutions which separated themselves only through their higher melting and congealing temperatures from the solutions that were liquid at ordinary temperatures. A further beautiful confirmation of this view was now furnished in the comparison drawn by Sir William Roberts-Austen between the behaviour of salt solution and that of liquid iron in congealing. The observations were new which were here recorded respecting the influence of occluded hydrogen upon the number and position of the critical points in the cooling curves of iron and steel; and further communications upon this subject would be eagerly looked for.

Professor HUGH L. CALLENDAR wrote that he had followed the work of this research as closely as his absence in Canada during the last five years would permit. In devising the differential plan of observation described in the fourth Report (Proceedings 1897, page 63), and illustrated by the curve given in Plate 2, he had no doubt that Sir William Roberts-Austen had discovered the most sensitive and promising method hitherto developed for investigating these obscure but highly important changes, which occurred in the cooling of iron containing various impurities that exerted so marked an influence on its mechanical properties. By this means effects had been detected which would have been beyond the ken of any less

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delicate method. The special advantage of employing the differential plan in the present instance was that it was not only extremely sensitive, but also peculiarly suited to the thermo-electric method of research. Recently he had himself had some experience in the application of a similar method with thermo-couples to an entirely different purpose: namely to the observation of the small cyclical changes of temperature which occurred in the superficial layers of the metal of a steam-engine cylinder (Proceedings Inst. C.E., vol. cxxxi, 1897, pages 147–268). The successful application of the thermo-electric method in that instance depended largely on the adoption of the differential plan; and it appeared to be even more peculiarly suited to the present investigation.

In page 51 the author had referred to some recent observations by Dr. Morris on changes in the magnetic permeability of iron about 600° C. or 1,100° F. Corresponding slight and peculiar deviations from the smooth parabolic curve had also been detected by the writer in the variation of the electrical resistance of pure and impure iron, which had been described in the Philosophical Transactions of the Royal Society, 1887, pages 201–3 and 226–9. These deviations appeared to take place at different temperatures in different specimens of iron; but no complete investigation or interpretation of them had hitherto been possible. It appeared likely that the new method of research would result in the explanation of their true significance.

With regard to the effect of gases dissolved in the metal, it was well known how remarkable an effect was produced in many cases by the presence of extremely minute quantities. It had been shown for instance by Mr. F. H. Pitcher, in some experiments conducted under the writer's direction at McGill College, Montreal, and communicated to the British Association in 1897 (Report, pages 763–6), that the magnetic hardness or "hysteresis" of commercial iron was greatly reduced, in some cases to less than one-third, by prolonged heating in a high vacuum, which had the effect of removing traces of occluded gases. The magnetic hardness was a quality of primary importance in the application of iron to all electrical purposes. The reduction of the hardness to one-third meant a large saving in power, especially in transformers. The elucidation of these peculiar low-temperature

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(Professor Hugh L. Callendar.)

critical points, recently discovered in the cooling curves of iron, would no doubt have the effect of explaining and systematizing much that was at present empirical in the treatment of iron for electrical purposes. Another point that had recently been attracting a large share of interest in the electrical world was the magnetic deterioration of samples of iron under certain conditions at comparatively low temperatures. By the application of some such delicate method of research as that now proposed, it might well be found that this effect was connected with the occlusion of gas, or with some obscure molecular change, of which the conditions could now be more hopefully studied.

Having regard to the importance of fixing the exact limits of temperature at which these molecular changes occurred in irons of different composition, the writer was inclined to suggest that it would be an advantage if the experiments could be conducted on a slightly larger scale: say with masses of 50 grammes instead of 5 grammes, or 1·75 ounce instead of 0·175 ounce. It would then be possible to observe these changes under more favourable conditions, and to refer the temperature measurements directly to the platinum-resistance scale, which was more definite and more accurate than the thermo-couple scale, especially at low temperatures. It would also be of great interest to determine how far these changes were reversible with change of temperature; and whether they took place between the same limits on heating a specimen as on cooling it. This might perhaps be accomplished by the electrical method of heating, which rendered it possible to apply heat in a regular and continuous manner. The changes occurring in the tempering of steel at comparatively low temperatures might also receive further elucidation by the application of the new differential method to the inverse process of heating.

Professor J. A. EWING wrote to express his sense of the great value of Sir William Roberts-Austen's remarkable series of Reports to the Alloys Research Committee. Probably no one, who was not himself familiar with the difficulties of scientific research, could admire sufficiently the skill which had been brought to bear upon

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the conduct of these experiments; or appreciate fully the immense amount of patient labour, of which these Reports were the outcome. The Institution was to be heartily congratulated on having work, so well worth doing, so admirably done. The Alloys Research Committee had shown their wisdom throughout in taking a wide view of their task, and in not attempting to narrow their enquiries down to points which might be held to be of immediate practical moment. In dealing with so large a subject as the nature and properties of alloys, it was essential to get at the general physical facts. The practical applications might well be left to follow in due course. The whole history of research went to show that it was impossible to say beforehand what would be the practical fruit of a physical enquiry. Points which at first sight seemed to have no more than a purely scientific interest had again and again proved to be fundamental in practical applications. The Alloys Research Committee were casting on the waters their bread of scientific knowledge, and he did not doubt that much of it would sooner or later contribute to the advance of engineering practice. The present Report dealt mainly with two distinct lines of investigation: in one, the changes of structure were traced during the cooling or heating of a metal, by recording the successive points at which there was evolution or absorption of heat; in the other, the microscope was applied directly to the examination of the structure. Sir William Roberts-Austen's devices for recording thermal change had been brought to a degree of perfection not before reached; and by this means new points of halt had been found in the cooling of electrolytic iron. As to the part probably played by hydrogen in these phenomena, his remarks were particularly interesting and suggestive. The importance of the microscope in metallurgical research was every day becoming more widely recognised. An engineer attempting the study of papers relating to this subject was at first somewhat bewildered by the terminology of the micrographers, finding himself confronted by many unfamiliar and forbidding "ites"; and perhaps the first impression derived from a casual glance at micro-photographs was that they were meaningless hieroglyphs. But when the matter was taken up seriously, and

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(Professor J. A. Ewing.)

especially when specimens of iron and steel were actually observed under the microscope, the subject was at once found to be full of promise, and the hieroglyphs were seen to have a definite meaning. The tiny fragment of metal under examination was found to be truly representative of the mass from which it came, and to give a world of information regarding the composition and history of the mass. The ancient phrase *ex pede Herculem* might fairly be the motto for the student of micrometallurgy. To himself the study was comparatively a new one; but by his own experiments he was already more than convinced of its interest and value. In experiments made with one of his students, Mr. Walter Rosenhain, which had recently been communicated to the Royal Society (Proceedings, 16 March 1899, pages 85–90), he had found that the microscope threw a flood of unexpected light upon the nature of plastic yielding in metals. The Institution he trusted would continue, through the Alloys Research Committee, to enjoy the privilege of being responsible for Sir William Roberts-Austen's work.

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MACHINERY FOR BOOK AND GENERAL PRINTING.

By Mr. WILLIAM POWRIE, *Member*, of London.

Until a comparatively recent period Typography was almost the only process employed in the production of books and other readable matter; but it is now largely supplemented by lithography, collotypy, &c., each requiring special machinery and appliances for their effective development. In fact the operations in a modern printing factory are specialized and carried on in departments, in a similar way to work in an engineering establishment; and a simple list of the various machines employed would fill several pages. As an excellent detailed description of a rotary newspaper-printing machine, and the method of producing a daily paper, has been given by Mr. John Jameson in the Proceedings of this Institution for 1881 (page 511), the author purposes dealing at present with the leading classes of Machines employed for Book and Job Printing.

Although the art and method of printing from movable types was invented about the beginning of the fifteenth century, it was not until the early part of the present century that printers' engineers and tool-makers began to produce power-driven machinery. Since then the improvement and development of printing machinery has been continuous, and more especially during the last thirty years, until the modern printing machine bears about the same comparison with the early ones that a first-class express locomotive does with the historic "Rocket;" and printers' engineering is now an important department of mechanical work. There is great diversity of details in the presses and machines used by typographic printers: some are of the "platen" kind, printing the whole surface of the sheet at once; and others are of the "cylinder" class, printing one line at a time, but

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revolving so rapidly that their production exceeds that of the platens. Some have one cylinder for printing one side of the paper only; while others have two or more, and print both sides at one operation, either from rolls or in sheets as may be desired. But a few leading principles are common to them all.

The aim of the printer is to produce on paper in one or more colours a correct representation of a given arrangement of type, or combination of engraved blocks or ornamental designs, which, while being printed from, are usually wedged fast or "locked up" securely in iron frames called "chases," the whole collection being called a "forme." To this end it is necessary to provide apparatus for covering the printing surface of the forme with a thin even coat of the colour in which the work is to be printed; and other apparatus by which the colour is transferred to the paper, so as to be always in the same position on a sheet of given size. When these operations are performed separately by the workman, the apparatus is usually in this country called a "press"; and when they are performed automatically by apparatus actuated by the turning of a single shaft, the combination is termed a "machine"; but in some other countries every such apparatus is termed a press and the maker a press builder, while here we have both press and machine makers, usually termed printers' engineers.

Most newspapers and magazines of large circulation are printed from webs of paper brought to the machine in large rolls, printed on both sides and delivered in sheets; but the bulk of book and job printing is done on machines which print one side of the paper only at a single operation, the sheets being taken singly from a pile. In platen machines the paper is usually fed or laid on and taken off by hand. In cylinder machines the sheets are usually delivered automatically: some are also self-feeding, but hand-feeding is still a common practice.

Hand Press.— For general proving or for printing small editions the hand press is still largely used. The general arrangement is as represented in Fig. 1, Plate 24, and Figs. 3 and 4, Plate 25, where B is a sliding bed or carriage for supporting the type

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forme; P is a platen for taking the impression, set down by a combination of levers L; and T is the tympan, and F the frisket frame, for holding the sheet in position while being printed. The forme is inked over by a hand roller, the sheet to be printed placed between the frisket and tympan, which are then folded down over the type; the carriage is slid under the platen, which is then pressed down on the paper by the levers with a force equal to about twelve tons in an average-size press, printing 36 inches by 24 inches.

Steam-driven machines were made on this principle thirty years ago, and largely used for book printing; but although they did good work they were slow, and the demand for greater speed has led to the development of cylinder machines, which, owing to the improvement in engineering tools and methods, can now be relied on to do quite as good work as the platens and a great deal more of it: so that platens have almost disappeared for large work, although the smaller varieties are used in increasing numbers for job printing.

Single-Cylinder Machines.—Wharfedale or single stop-cylinder machines have been for many years the most popular for book and job printing; their general arrangement is as shown in Figs. 5 to 11, Plates 26 to 29. In designing a machine of this class, the first thing to decide is the size of sheet it is to be capable of printing, and then how many inking rollers shall clear or pass over a full-size forme; these data determine the travel of the carriage, size of cylinder, and total length and width of the machine. The forme must clear the cylinder grippers at one end and the last inking roller at the other, while the circumference of the cylinder must coincide with the stroke or travel of the carriage, and the length of the forme over the chase settles the width of the machine. As it is usual to put the crank-pin in the driving wheels, the length of stroke required determines their diameter; and they in turn fix the height of the carriage, the ink-table having to pass over the top of them. The other working parts are arranged as the experience of the designer may suggest, and the frame is made to suit his arrangements. The frame is on the box principle, with two sides,

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two ends, and one or more cross stays in the centre: all securely held together by tight-fitting bolts.

The carriage which supports the forme and ink-table, Plate 27, runs forward and backward on two, and in large machines on four, sets of anti-friction live rollers or bowls R, running on rails or tracks, which are usually planed after being bolted in position, in order to ensure accuracy. These rollers are kept at regular distances apart by coupling-bars on each side of them, Plate 28, and are compelled to run at the proper speed by being coupled to the rack-wheel shaft. The carriage is propelled by the rack or traverse wheels W, which are fitted with smooth flanges to run on rails fixed securely to the frame, and gear simultaneously into racks both top and bottom; the bottom racks are fastened to the rails, while those on the top are secured to the underside of the carriage. The rack-wheel shaft is coupled by a connecting-rod to a crank-pin in the main driving-wheels, and with its wheels runs forward and backward as the driving wheels revolve; the racks on the carriage compel the latter to move in the same direction through twice the distance. The printing cylinder is driven by the carriage, which has a toothed rack at each side, driving spur wheels on the cylinder ends. One of these wheels is securely fastened to the cylinder, while the other runs loose when the cylinder is at rest, the fast wheel having a portion of its teeth planed off at the underside to clear the carriage rack on the return stroke. The loose wheel is coupled to the cylinder by a pawl clutch, Figs. 8 and 9, Plate 29, so arranged that it allows the wheel to run either loose or securely attached to the cylinder as required; and an automatic cylinder-check and double-rolling motion D are fitted, which when required prevent the pawl from dropping into position to take the cylinder through each alternate revolution, so that the forme then gets twice the usual amount of inking. Moreover, by touching a small lever, the attendant can at will prevent the cylinder from revolving. At each end of the cylinder surface, a belt of about 1½ inch width is made exactly the diameter of the pitch line of the cylinder wheels: so that these belts will roll without slip upon the bearers which are secured on the carriage. The centre part of the cylinder, being the printing surface, is made 1–16th inch smaller in diameter than the end belts, in order

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to allow space for a few sheets of paper and a calico covering, for holding the overlays or patchwork "make-ready"; the latter is required to make up for the uneven surface of the forme, and to bring up the printing properly on the paper. The cylinder surface is ground dead true after turning.

The strain of the pressure required in printing comes principally upon the cylinder and the frame cross-stay S immediately under it, as the carriage and forme are like a fine wedge driven in between these to separate them. The cylinder is stiffened by ribs cast inside, and has a strong steel shaft right through, Plate 28; while the centre cross-stay is stiffened by a heavy bottom flange, Plate 27, and rests, as do the other stays, on planed seatings projecting inwards from the frame sides. The bolts are thus relieved from pressure, and have only to hold the parts together.

The ink, which is usually made of lampblack or other colouring matter, is ground up in boiled or blazed linseed oil, contained in a narrow trough, called the ink-box, duct, or fountain, Plate 27, placed across the back end of the machine; one side of the box is formed by a cast-iron roller called the ink-cylinder, and the other by a triangular piece of cast-iron called the duct-knife, which is really a scraper. The ends of the ink-box are plates, fastened by screws to the ends of the knife, and lapping over shoulders turned on each end of the ink-cylinder to prevent the colour from escaping. The duct-knife is adjustable by screws in its back edge, and can be set close to the ink-cylinder or at any required distance from it, so that the latter may be coated with colour to any thickness desired. The colour is taken off the ink-cylinder by a small vibrating composition-roller, and is laid on the ink-table or distributing-drum according to the class of machine. An adjustable ratchet-motion causes the ink-cylinder to revolve when the duct roller is in contact with it, whereby a portion of its coat of colour is transferred to the duct roller, and over more or less of its surface as required. The distributing drum revolves in contact with two or three composition-rollers placed on the top side of its circumference, and is compelled to move endways a few inches to and fro by a lever and cam or by a worm-wheel and crank; the result of this lateral movement

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combined with its rotation is to spread the colour in an even thin film all over its surface. Underneath the drum is another vibrating roller, which takes colour from the drum and deposits it on the ink-table or "slab." The latter is an iron plate secured upon the end of the carriage; its top surface is finished quite smooth, and is set to the same height as the face of the forme. In machines for the commoner sorts of printing, the colour is transferred from the ink-cylinder to the ink-table direct, without passing over a distributing-drum, which is omitted from such machines. The ink-table moves forward and backward under the rollers, and has the colour equalised over its surface by the distributing rollers or "distributors," which are caused to traverse laterally over its surface by being placed diagonally across the machine. The forme rollers or "inkers" take up a coating of colour from the ink-table as it passes under them; and this coating is further distributed or equalized by the "traversing riders," Plates 27 and 29, which are made of steel tube accurately turned and polished, and are compelled to move endways to and fro by a suitable crank-motion. The colour is ultimately deposited by the inkers on the face of the forme; and finally by the pressure of the cylinder is transferred to the paper to be printed. The whole of the inking and distributing rollers are made of steel tube, with ends welded in, and covered outside along the centre portion with a composition made of a mixture of glue and treacle or glycerine, cast hot in accurately bored and polished moulds.

In order to produce good printing, especially if the design is in several colours, it is necessary that the cylinder and carriage should always come into contact in exactly the same relative position, and that the cylinder start and stop at exactly the same place in each revolution. When the carriage is made a good sliding fit in the frame, and the cylinder fits its bearings so that there is no end play, and the teeth of the wheels and racks are of correct size and shape, and when also the bearers are the proper height and in contact with the cylinder belts when in motion, then the carriage and cylinder will move so accurately that the cylinder may be run repeatedly over the forme without showing more than a single impression. When the sheets to be printed are laid against stops on the "grippers," the above is sufficient

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to ensure good "register;" but in the machines now described the stops or "lays" are usually attached to the feed-board, and are quite unconnected with the cylinder, so that any variation in the position of the cylinder, when the grippers close on the sheet, spoils the register. To prevent such an occurrence, these machines are fitted with a pushing motion, which presses the cylinder back to a dead stop before the grippers close on the sheet, Plate 28, and Figs. 10 and 11, Plate 29. On the inner side of the brake-wheel rim is cast or fastened a projecting lug A, which is fitted to fill the space between two movable levers B and C, so arranged that, when the cylinder revolves in the direction of the arrow, the projection A on the brake wheel depresses the front lever B, Fig. 11, and passes clear over it, allowing the lever to rise up to its previous position. When the cylinder stops, the other lever C, which has been drawn back for allowing the wheel to pass, Fig. 11, is pressed forward by a cam and lever arrangement, and pushes the brake wheel and cylinder back, until the projection A on the wheel is hard up against the front lever B, Fig. 10.

The sheets to be printed are laid in a pile on the front part of the feed-table. They are removed by the operator singly to the back portion, and laid in contact with the "lays" at the gripper edge and at one side. This portion of the table is hinged at its front edge, and the back edge is raised by a cam and lever arrangement until the sheet is in contact with the gripper edge of the cylinder; the grippers then close on it, the cylinder revolves, and the printing is completed.

In the early days of cylinder printing-machines, the sheets when printed were removed by hand from the cylinder, and deposited in a neat pile on the delivery table with the printed side up. The boy or girl attendant usually transported the sheet with a rapid movement through the air, which caused it to float down on to the pile upon the table. This came to be termed flying the sheet; and the mechanical apparatus which has now generally replaced the human attendant is called a "flyer," Plate 27, and Fig. 10, Plate 29. A cylinder of wood, half the diameter of the printing cylinder, and provided with grippers to alternate with those of the latter, is placed in a convenient position and geared with the printing cylinder; cams for actuating

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both sets of grippers are so arranged that, when they are passing the plane in which lie the axes of both cylinders, the main grippers open and the flyer grippers close on the sheet, Fig. 10, which is then carried round the small cylinder until the latter stops and the grippers are opened, when the sheet is in position between two or more rubber-coated rollers, which are adjusted on a spindle to suit the unprinted margins of the paper. These rollers apply sufficient pressure to retain the sheet in position and compel it to move onwards when the flyer cylinder makes the next revolution; but, instead of going round with the cylinder, the paper passes off upon a series of carrying tapes, which are put in motion by the flyer cylinder, and at the proper time is lifted by the "fan," which may be likened to a large oblong hand, with wooden laths instead of fingers. The fan transfers the sheet to the pile on the delivery-table, turning it upside down on the way, and so delivering it with the printed side up. In order to facilitate "making ready," the flyer apparatus is so arranged that, by depressing a lever, it may be elevated bodily for giving ready access to the cylinder, as shown by the dotted lines in Plate 27. Automatic delivery is now the rule, but automatic feeding is still the exception; and although some highly ingenious apparatus has been tried, and in certain cases found to answer well, yet the great diversity of circumstances under which printing machines are used, and the variety of papers printed, make the production of a satisfactory feeder at a moderate price a difficult problem to solve. Considering the number of clever minds that have been and are devoting attention to it, and the stimulus of stringent factory regulations, the time is probably not far distant when automatic feeding will be as common as automatic flying; and a pile of plain paper deposited on the feeder table will be printed and deposited in a pile at the delivery end of the machine, without being touched by hand.

The class of machine just described, with various modifications of detail, has enjoyed a great popularity among British printers during the last twenty-five years, as a good all-round machine; but, for printing illustrations or work with solid masses of colour, the inking is not satisfactory. Although this has been remedied to some extent by double rolling, or placing inking apparatus

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at both ends of the machine, these methods reduce the speed and rate of production.

Fine-Art Machines.—Within the last few years the preparation of printing blocks by photographic processes has so reduced their cost, that books and magazines are now more plentifully illustrated; and the demand for a better kind of printing machine has become imperative. Plates 30 to 32 represent some of the fine-art machines now coming into favour for this class of printing. These machines are substantially built. The defective inking of the Wharfedale machine, Plate 27, arises from the forme rollers receiving colour only when the ink-slab runs under them; and this intermittent supply, although sufficient for open type, soon gets exhausted when large surfaces have to be covered, and the rollers are almost bare before they have gone over the forme twice. In Plate 32 the flat distributing-slab or table is replaced by cylinders in contact with the forme rollers, ensuring a continuous and even supply of colour to the forme, which enables the machine to be worked to its utmost capacity. The sheets are fed in at the top of the cylinder to lays attached to it, as shown in Fig. 15, Plate 33; and the lays are adjustable by screws, which greatly facilitates obtaining correct register. By dispensing with the ink-table and placing the inking apparatus nearer to the cylinder, it is easier to put the forme into position on the carriage, and to get at it for cleaning and adjustment.

To facilitate changing and cleaning the inking rollers, they are divided into two sets, Plate 32; and by a rack and pinion arrangement the ink-box and distributing rollers can be moved backwards bodily on the frame, leaving the forme rollers more accessible to the operator, as shown in Plate 31.

The flyer apparatus can also be detached and moved away from the cylinder to facilitate "making ready," Plate 31; and the flyer drum, instead of being a hollow cylinder of wood, is a series of gun-metal rings with grippers attached, the rings being fixed on a shaft. This arrangement is less liable to get out of truth, and makes less noise in working, than the hollow wooden drum.

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To ensure smooth running at the increased speed now required, these machines, as well as the best of those previously described, are fitted with air-buffers, which take up the momentum of the reciprocating carriage and give it an impulse to return, Plates 27 and 32. (*See also* page 120.)

Two-Revolution Machines.—In the last two machines, which are of the stop-cylinder class, the cylinder stops after each impression, and remains at rest until the carriage has returned to the original starting position. But the desire for increased speed has led to the introduction of two-revolution machines, in which the cylinder is continually in motion while the machine is at work, and makes two revolutions for each sheet printed, as shown in Plates 34 to 36. Although this class of machine was in use in this country over twenty-six years ago, it met with little favour until quite recently, when introduced in an improved form as a novelty from the United States.

The type carriage in these machines is propelled in several different ways; but the arrangement shown in Plate 36 seems to have found most favour up to the present with British printers. Instead of the rack-wheel travelling forward and backward while in gear simultaneously with both the top and bottom racks, as in the machines previously described, it revolves continuously in one direction, and being mounted on a sort of cradle-frame A has a small vertical movement, which allows it to engage alternately with the top and bottom rack. Attached to the under side of the type carriage is a rectangular frame B, carrying the driving racks; and near their ends are two vertical flaps or shutters C turning on vertical pivots, which are opened and shut transversely at the proper times by the bowls or rollers D D and cam plate E. As the end of the frame B nears the rack-wheel, the shutter C opens, and allows the bowl F, carried by the rack-wheel, to pass it and get into the slot formed by the end of the frame and the edge of the shutter, which has now closed. Then the rack-wheel moves away from the rack it is driving, and the bowl F takes charge until it comes round to the bottom of the slot, when the rack-wheel engages with the

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other rack, the shutter opens, and the carriage proceeds on the return journey. These movements are repeated at each end of the stroke.

As this method of driving gives an even steady speed of travel, with only a short stay at the ends, the momentum of the carriage is considerable, and is taken up at each end of the frame by the air-buffers, Plate 36, which soften the shock at the ends of the stroke, and give the carriage an impulse for its return. The cylinder is not driven by the carriage, as in the machines previously described, but by independent gearing from the driving shaft, whereby a smooth steady motion is produced; and in order to ensure accurate register, a few teeth on the cylinder and type carriage engage with each other when the printing surface is about to meet the forme. The sheets are fed in to the top of the cylinder as in the fine-art machines; but the lays are attached to the frame, and are removed out of the way when the grippers seize the sheet, which is carried round by the cylinder, printed, and delivered by a flyer in the usual way.

The inking arrangements of these machines are generally similar to those of the stop-cylinder machines; but the distributors are arranged in pairs, with a polished steel-tube roller between, geared to run continuously, which materially assists the distribution of the colour. During the printing, the cylinder is pressed down and held in contact with the forme by a pair of toggles or eccentrics E, Fig. 16, Plate 33; and, when the forme has passed under it, the eccentrics are released, and the cylinder is raised about a quarter of an inch by helical springs at the top of the impression rods RR, in order to clear the forme during its return stroke. The bowl B, carried at the end of an arm A which turns loose upon the eccentric shaft E, runs in the groove of the impression cam C, which revolves in the direction of the arrow. On the spindle of the bowl is centred a quadrantal jaw-lever J, having on its underside a jaw engaging the impression arm I which is fixed upon the eccentric shaft E. In the jaw lever is fixed a pin P, which works in a quadrantal slot in the check lever K, keeping the jaw engaged with the arm I while both move together through nearly a quadrant of a circle and back during each revolution of the cam C, thereby rotating the eccentrics E through the same angle forwards and backwards for applying the

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pressure upon the forme and relieving it again. When it is desired to miss printing without stopping the machine, the cylinder is retained in its highest position by disengaging the jaw lever J by means of the foot lever F, which is depressed by the treadle T at the feeder's stand. The check lever K and the jaw lever J are thereby raised into the positions shown by the dotted lines: so that, while the impression cam C continues to revolve, the jaw lever J works clear of the impression arm I, and the eccentrics E are not brought into action for depressing the cylinder. The treadle T is held down as long as required by the pin N catching underneath the foot board; when this is released by pushing it aside with the foot, the treadle and foot lever F are raised to their original position by the helical spring S. The jaw lever J then drops into gear again with the impression arm I.

Two-Colour Machines.—The machines previously described are designed as single-colour machines, although two or more colours may be printed on them at the same time with special appliances; but where much work in colours is done, such as posters, showcards, labels, &c., it is preferable to employ two-colour machines, as represented in Plate 37. These are designed on the same general principles as the single-colour machines represented in Plate 26, but are double-ended, and the cylinder revolves twice for each complete impression. The carriage is double, having space in the centre for two formes; and an ink-slab is fixed at each end. The inking arrangements are similar to those on the single-colour machine; there is a complete set at each end, and for each colour in the printing. The formes are inked up by passing under the inking rollers, as in the stop-cylinder machines; and the cylinder with the sheet of paper to be printed rolls over both formes before it stops; thus a two-colour impression is obtained at each travel of the carriage. The sheets are fed in and delivered as in the single-colour machine; and if more than two colours are required in the design, the sheets can be put through the machine as often as required, and completed as in the other machines, with the advantage of having two colours put on at each printing. If two-colour work falls off, such

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a machine can be used as a single-colour machine; but the production will be less, because owing to its greater length it cannot be worked at the same speed.

Perfecting Machines.—The first successful cylinder printing machine, which printed the issue of "The Times" for 29th November 1814 for the first time by steam power, printed the paper only on one side in a single passage through it, being what is called a single-side machine, although it had two cylinders; but the necessities of newspaper and book printers soon led to the introduction of machines which "perfect" or print both sides of the sheet in each complete revolution, and are known as "perfectors."

These machines differ in their arrangements and details, but may be grouped generally in two classes: those with large cylinders making one revolution; and those with small cylinders making two revolutions for each sheet printed. They are used for book and magazine printing, where the editions are large and the sheets have to be printed on both sides. The machines mostly in favour with British printers for ordinary work are those with the large cylinders, of which Plate 38 shows the general arrangement, and Plate 39 is a sectional view showing the arrangement of the cylinders, and of the tapes which guide the sheets through. The type carriage is here driven by a horizontal pinion, Plate 39, secured to the top of a vertical spindle, and acting on a rack with two flat sides and round ends, which is secured to the type carriage, but is free to move transversely: so that the pinion may gear into each side of the rack alternately, and cause the carriage to move first to one end and then to the other. Each type-forme comes under its own cylinder, and the sheet of paper is printed first on one side and then on the other.

The cylinders run in fixed bearings adjustable vertically to suit the impression, and the registering drum is also adjustable vertically, so as to vary the length of the tapes between the inner and outer forme-cylinders, and also to alter the position of the sheet on the latter while being printed, in order to ensure the pages being exactly opposite each other on both sides of the paper. The printing surfaces of the cylinders are covered, as in the single-cylinder machines, with calico for the

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"overlays" and a few sheets of paper or a blanket, according to the class of work and the result required; the remaining portion of their circumference is made about ¼ inch less in radius, so as to clear the formes during their return. The sheets to be printed are laid in a pile on the feed-table, which is a fixture, and are fanned out at the front: so that the feeder has but a small distance to move them, and usually "strokes" them down to the front lay marks with a hard wood or bone stroker. The gripper drum, which is about one-third the diameter of the printing cylinders, opens its grippers each alternate revolution. These seize the sheet by the front edge, and draw it forward into the tapes; then the grippers open, and the sheet held between the two sets of tapes is carried round the cylinders until it is printed on both sides, and deposited on the receiving table. The inking arrangements are similar to those on the two-colour stop-cylinder machine, as there is an ink-box or duct, with ink-table, distributing, and inking rollers, at each end of the machine, one set for each forme.

In these machines as usually constructed, only two inking rollers clear a full-size forme, which is not sufficient for good illustrated work; but the inking may be improved by applying a continuous inking arrangement similar to that shown on the fine-art machine, Plate 82. Flyers are now also frequently attached for delivering the printed sheets, and air-buffers for softening the shock of the type carriage at the end of each stroke.

In the small-cylinder two-revolution class of "perfectors" the cylinder bearings are fixed at both sides to slides, which move vertically for raising the cylinders above the formes during the return of the type carriage. The slides are held down by powerful knee-joints while the cylinder is in contact with the forme printing the sheet, and are raised by springs, as in the single-cylinder machine. The cylinders are placed close together, and both are fitted with grippers; those on the first or "inner" cylinder take charge of the sheet until after it is printed on the first side, when the "outer" cylinder grippers take charge until the second side is printed; after which the sheet is shot out upon the receiving table or delivered by a flyer, according as the machine may be arranged.

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The type carriage is propelled sometimes by an upright spindle and horizontal rack, similar to the arrangement in the single-revolution perfectors, Plate 39; but more frequently by a vertical rack securely fastened to its under side, and driven by a pinion on a horizontal shaft with a universal joint, so arranged that the pinion gears into the top side of the rack-teeth during the travel one way, and into the under side during the return: this arrangement is usually termed the "mangle motion," owing to its early use in propelling horizontal mangles for smoothing cloth. Other methods are also in use, such as that for driving the carriage of the two-revolution single-cylinder machine shown in Plate 36; but the vertical rack in some form is in most favour, because the carriage can then be better supported near the centre to resist the pressure of the cylinder on the forme.

These machines have inking arrangements generally similar to the others, but are usually made with four inkers or forme rollers to clear a full-size forme; this, together with the greater stiffness of the carriage in the centre, makes them better suited for printing illustrated work. They are usually not run at so high a speed as the large-cylinder single-revolution machines; and they are so arranged that "set off" sheets can be fed in, to prevent the ink on the first side printed from "setting off" upon the second cylinder or adhering to it and smearing the next sheet.

Platen Machines.—Most of the small job printing is now done on platen machines, of which there is a great variety, although the leading principles are common to all; and Fig. 2, Plate 24, may be taken as representative of the class. The body of the machine is a strong box-casting, as shown in the section, Fig. 23, Plate 40, with bearings for the shafts, and seatings for the brackets carrying the outstanding parts. The forme is secured by a spring clip in a recess V, which has been finished to a smooth accurate surface; and, instead of its moving horizontally under the inking rollers as in the cylinder machines, the rollers pass down and up over it. The colour is put into the ink-box I, which is adjustable by screws; and is transferred by the roller D to the circular ink-plate S. The latter is moved round

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a little at each impression by a ratchet and pawl motion, so as to distribute the colour equally over its surface. The three rollers R act both as distributors and as forme rollers; for when they pass over the ink-plate they equalize the coat of colour on its surface, as well as take on themselves a coat to be transferred to the face of the forme. Below the forme there is an extra distributor plate P, which receives colour from the same rollers R, distributes it by a traversing movement, and restores it to the rollers, so that they can give a fresh touch to the bare places of the forme on their way up again.

In the working of platen machines the sheets of paper are usually both laid on and taken off by hand. The operator takes a blank sheet from the pile on the table with his right hand, and lays it up to the gauge-pins or "lays" while the platen is at rest in the position shown; and removes the printed sheet with his left hand, after the platen has brought it into contact with the forme and has returned to its first position.

The platen, which is finished to an accurately smooth surface, rests on wedges B fitted into the platen back. The wedges are adjustable by screws, as shown in Fig. 24, so that any side or corner of the platen can be advanced as may be required, in order to give an equal impression all over the surface of the forme. The face of the platen is covered with a thin cloth or a few sheets of paper, or both, as is the printing surface of the cylinders of the other machines; and is "made ready" in the same way, by pasting pieces of paper opposite the low places of the forme, so that the impression may be of equal depth all over. The sheets are strained tight, and held in position by clips C at each side of the platen. The lays are attached to the platen covering; and the sheet to be printed is held in position and removed from the face of the forme by two thin pieces of steel F, called frisket fingers. When the platen is moving forward, these come down and press on the end margins of the sheet; and when the platen is returning to the feeding position, they are raised to release the sheet. The platen is balanced by long helical springs; and the pressure upon it while taking the impression is intensified by a toggle-lever arrangement T, so that in an average size machine,

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printing sheets 18 inches by 12 inches, the pressure will amount to about 20 tons when printing solid formes.

In platen as in cylinder machines it is sometimes desirable to prevent printing without stopping the machine. For this purpose, instead of compelling the platen to remain at rest, as the cylinders do, a "throw-off" arrangement is provided, Fig. 24, which sets back the wedges, and allows the platen to recede about a quarter of an inch, thus preventing the paper from coming in contact with the forme. This throw-off arrangement is used to prevent spoiling a sheet when not laid correctly, or to give double rolling when required; but when the bulk of the work is heavy, it is much better to provide machines with ample rolling power, so as to keep up the rate of production.

Printing on Dry Paper.—The strength of machines has been increased, in consequence of the change from printing on damp paper, which was customary twenty years ago, to printing on dry paper without leaving any marks of impression on the back, which is more general now. Also the profusion of illustrations produced from flat-surface process-blocks demands greater accuracy in the surfaces and adjustments of the printing machines than was previously considered necessary. The older presses and machines, designed to print with a blanket between the cylinder or platen surface and the paper, produced with careful management fairly good printing; but it was frequently so much embossed as to resemble books for the blind, and the sheets had to be pressed or rolled afterwards to make them flat. The modern machines, using a few sheets of hard paper instead of a blanket, turn out flat work without any sign of impression on the back.

Working Pressure.—A common working pressure in a lithographic printing-machine, working stones or flat metal plates, is about 200 lbs. per inch width of impression, and the line of pressure is not more than $\frac{1}{4}$ inch broad. The pressure per square inch of surface printed is therefore about 800 lbs. In typographic formes with illustrations, from a quarter to half the surface in contact with the cylinder or platen will be under pressure at the same time: so that, in order to obtain

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the same result, the pressure will be 200 to 400 lbs. per square inch. The old "Albion" press, with a leverage of 200 to 1, and a maximum pull on the handle of 200 lbs., subject to an allowance of one-fifth for friction of parts and resistance of spring, gave only 53 lbs. pressure per square inch on the forme, which is inadequate for present requirements. Many of the older platen and cylinder machines gave similar results. One popular job platen, with a leverage of 150 to 1 and a maximum pull at the fly-wheel rim of 50 lbs., gives only 58 lbs. per square inch effective pressure on the forme. The job platens described in this paper with a leverage of 400 or 480 to 1, according to size, and a maximum pull at the fly-wheel rim of 80 to 90 lbs., give an effective pressure on the forme of 200 to 400 lbs. per square inch; and both these and the cylinder machines are quite equal to a pressure of twice that amount if required, for exceptionally heavy work.

Grinding of Surfaces.—The grinding of the cylinder surface dead true, as also of the bowls or live rollers under the type carriage of cylinder machines, which is now done where first-rate work is turned out, is found to be a great improvement for printing from fine process-blocks, where a single thickness of tissue paper may make all the difference between first and second-class printing.

Air Buffers.—As previously described, high-speed reciprocating flat-bed machines are frequently fitted with some provision for cushioning the momentum of the type-carriage and its connections at each end of the stroke. Springs having been found unreliable for this purpose, air-buffers are now coming more into favour, Plates 27, 32, and 36. With these it is easy to adjust the resistance to the speed and moving weight; they are not liable to get out of order, and they effect a notable improvement in smoothness of running, especially in machines having the carriage propelled at a uniform speed and turning the ends quickly. A quad demy two-revolution machine, running at 1,500 impressions per hour, may serve as an example of the need for cushioning. The type carriage, with its apparatus and a type forme, weighs about 14 cwts., and travels at about 4½ feet per second: so that the momentum at the end of the stroke is about equal to 3 tons moving at one foot per second,

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which, if not cushioned, would produce a blow on the propelling gear and framing at each end of the stroke or travel. In the machine under consideration the shock is taken up by two air-buffers at each end, 5 inches in diameter, with cylinders 15 inches deep, into which the pistons enter 12 inches, and produce a maximum air-pressure of 50 to 60 lbs. per square inch, equal to a resistance of about 2,000 lbs. at each end. As this is an increasing resistance through the last 12 inches of travel, the carriage is stopped smoothly, and receives considerable impulse for the return.

As the variety of work and the size of the editions, or the numbers of similar sheets printed, have greatly increased during the last twenty years, there is now more scope for special machines designed for special work. But the principal demand is still for generally useful all-round machines; and those now described may be taken as fairly representing the machinery employed for book and general or job printing in British factories at the present time.

Discussion.

Mr. POWRIE exhibited one of the platen job-printing machines, Fig. 2, Plate 24, and showed its action in working. Also specimens of the composition used for covering the inking and distributing rollers (page 108); and of the accurately bored and polished moulds for covering with the composition the steel tube forming the body of the rollers; and of the rollers so covered. Also specimens of printing from the following machines:—platen, Wharfedale stop-cylinder, fine-art stop-cylinder, two-revolution single-cylinder, and Wharfedale two-colour.

Mr. JOHN SOUTHWARD said that, as a printer and not an engineer, he had listened to the paper with the greatest interest, and had derived a great deal of instruction from it. Apart from its value as a comprehensive and accurate review of the best kinds of printing

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(Mr. John Southward.)

machines which printed from types on a flat bed, he thought it would be of service to the printing industry by bringing this subject before a body of mechanical engineers, because he believed there were few industries which had been so much overlooked by engineers as that of printing. For a great many years so few practical improvements had been made in printing machines in this country that foreign manufacturers had got ahead of English makers in many ways. Naturally printing-machine manufacturers would say that they provided as good machines as were called for, and that they must conduct their business on a commercial basis, and that better machines had not been provided because they were not in demand. Similarly printers also might say that there was not a public demand for such high-class work as would require improved machinery; and it must be confessed that the general kind of printing which was done by the machines described in the paper had always been in a backward state in this country. On looking back at the report of the jurors of the Great Exhibition in 1851, it would be found that an international jury had then been compelled to call attention to the inferiority of English printing. At the next Exhibition in 1862 a Frenchman, M. J. C. Derriey, came over to London with some remarkable specimens of type founding, and showed that there were many possibilities in plain and ornamental type-founding which were really not believed or realised at that time. His improvements found little acceptance in England then, perhaps hardly any; but they were taken up abroad. The extraordinary effects which he had produced were imitated in Germany, and still more largely in America; and they laid the foundation of the superiority of American type-founding, which some printers thought was maintained to the present day. At any rate English printers did not avail themselves then of the Derriey types, and did not improve their class of printing. Coming sixteen years later to the Paris Exhibition in 1878, it was found that the Americans had meanwhile made marvellous strides forward, in regard both to type-founding and to printing machinery. A model printing office was put up in the 1878 Exhibition, which no doubt had surprised many of the visitors. In 1883 there was an exhibition of printing in the Agricultural Hall, Islington, London, at which he had been

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one of the jury; and the inferiority of English printing was demonstrated. Perhaps the only piece of really fine printing in that exhibition was the one which gained the first prize. It was done in fifty-three workings; every sheet of print had to go through the press fifty-three times. In 1889 an international exhibition of printing was held at Stationers' Hall in London; and the English specimens of general printing were still inferior, as was acknowledged by the Lord Mayor, who presided, and by Mr. now Sir Henry Bemrose. In 1889 there was again another exhibition, showing that English printers had not even yet made much progress in fine printing. Within the last ten years however improvements had been made in machinery, which printers had really been compelled to adopt. The method of making photographic blocks had largely affected the modes of printing, and had necessitated extensive modifications in many of the machines. The fine-art platen and cylinder machines described in the paper would hardly have been adopted, if half-tone blocks had not been invented; because half-tone blocks required better inking and heavier pressure. As had been plainly shown by the author, one of the great faults of earlier printing machines was that they did not exert pressure enough; and in some of the fine-art machines the inking had since been greatly improved. Having himself been engaged for so many years in connection with the art of printing, he had no idea of depreciating it, but only of suggesting that mechanical engineers in general, as distinguished from printing-machine manufacturers, should pay more attention to the subject. There were many excellent printers' engineering firms, who could turn out unexceptionable printing machinery to meet the general demand as it arose; but he did not know of any trade whose improvement had been less completely promoted than that of printers. In London there was an important and influential Association of Master Printers and Kindred Trades, comprising some of the most eminent firms, which in its corporate capacity had sent out on 29th May 1897 the following appeal:—

"The Committee have observed with regret the great increase in the amount of foreign-made machinery used in connection with the printing trades; and they have decided to draw the attention of

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(Mr. John Southward.)

English printing engineers to this, with a view to finding a remedy, if possible, for so unsatisfactory a state of affairs. In their opinion the increasing preponderance of foreign machines used in the printing trade is due to the greater inventive and administrative ability which foreign printers' engineers display; and as the interests of the English printers' engineers are identical with those of the master printers, the Committee desire to ask whether something cannot be done for enabling printers to place in this country their orders for first-class machinery up to date, instead of having unwillingly to send them abroad." This appeal would serve to show that printers had complained that engineers had not provided them with exactly the machines which were wanted; and also to show that it would be a fine field of enterprise if scientific engineers would devote their attention to printing machinery more than they had hitherto done.

Mr. ALEXANDER NORTH fully agreed with the statement in the last sentence of the paper, that the principal demand was still for generally useful all-round machines. There was no doubt that most printers needed a machine which could be used for any and every ordinary purpose. As to automatic feeding (page 110), if engineers could supply printers with a reliable self-feeding apparatus, there was no doubt that in the course of a few years it would be used all through the printing trade. To produce such an apparatus which would work efficiently, a great deal of time and attention would have to be bestowed upon it. Whenever it was successfully matured, there would be a great demand for it. As far as he was himself concerned with printing, he should be glad indeed to see such a contrivance; and as soon as ever an effective self-feeding apparatus was brought out, he would be one of the first to examine its merits.

Mr. POWRIE thought that, as regarded lack of enterprise (page 122) on the part of engineers in supplying printers with improved machinery, if it had been possible for printers to be a little less anxious about price and more anxious about quality, perhaps they might have been better served by engineers. It had given him great pleasure to prepare the paper, which might have been extended

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to much greater length without by any means exhausting the subject. In its present form he should be very glad if it proved of service to those interested either in the printing industry or in the manufacture of printing machinery.

The PRESIDENT conveyed the thanks of the Institution to Mr. Powrie for the labour he had bestowed upon the paper, which gave so excellent a detailed description of the mechanism of several of the principal kinds of typographic printing machinery.

Mr. CECIL CLAY wrote that he thought there were many points upon which practical printers might derive great advantage from the wider experience of mechanical engineers. For instance, the two-revolution machines, described in page 112, in their improved and accepted forms are to all intents and purposes an American importation, and are being largely adopted by English printers. No doubt practical printers are able to form a fairly sound judgment as to the merits of these and other machines, in respect of their actual printing capabilities, that is, their capability to print true and to give an efficient ink-distribution, and their rigidity to withstand the constant and the varying pressures to which they are subjected. But a further consideration of great importance to the user is durability, inasmuch as the price of this American machinery is practically double that of machines of the same size of the ordinary English pattern. It is on this point that information is required by printers, and in the writer's opinion it is to be sought from mechanical engineers rather than from practical printers themselves. From a mechanical point of view the ultimate decision respecting a two-revolution press lies in the method adopted for driving the bed of the machine. There are at least three more or less distinct movements in use at the present time for accomplishing this object, and innovations are always in prospect. The three may be readily identified under the following descriptions:—first, the upright-spindle motion; second, the mangle motion; third, the motions of the

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(Mr. Cecil Clay.)

Century and Miehle printing machines, which are two modifications of the mangle motion, dispensing with the universal joint. Presumably all three cannot be perfect alike, or there would seem to be no necessity for more than one of them; and it should surely not be outside the range of mechanical engineering to pronounce which one is mechanically better than the other two. Although the printer may be quite satisfied that every one of the American machines offered to him is ideally perfect, so far as printing is concerned, yet he may have serious doubts as to the perfection of its mechanism, and as to the durability of the latter. The problem is simply to drive the machine bed, weighing with its apparatus and type forme about 15 cwts., through a distance of five feet and back, some two thousand times in one hour. Of the three methods in use, which is the best from a mechanical point of view for performing its task smoothly, efficiently, and with least wear and tear?

The great difference between English and American printers' engineers appears to the writer to be that the latter seem to go into the details of printing, and to find out what it is that printers want, and then to make it for them. It can hardly, he thinks, be a question of price, in view of the fact that the increased price asked by American makers is immediately given, as soon as ever they produce the right machine. This applies not only to the printing machine itself, but also with equal force to all printers' machinery. Printers know what they want, but in most cases cannot experiment for themselves; they need the services of the printers' engineer to supply their requirements.

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MEMOIRS.

Alexander Bertram was born at Salton, Haddingtonshire, on 9th November 1853. He served his apprenticeship from January 1869 to November 1874 in the fitting shop and drawing office of the Wigan Coal and Iron Co., and during that time studied also in the engineering classes of the Wigan Mining and Mechanical School. He remained in the drawing office till February 1877, when he superintended the erection of pumping and hauling machinery at their Ladies Lane Colliery, Hindley. From October 1877 to the end of 1878 he was employed as foreman over outside fitters; and on 1st January 1879 was appointed superintendent of machinery under the Mines Regulation Act, for a large section of the company's collieries. At the end of 1879 he became mechanical engineer to the company, having charge of all the machinery connected with their collieries producing two million tons of coal per annum, and with an extensive steelworks and a range of ten blast-furnaces. In order absolutely to prevent overwinding at the collieries, and also to prevent winding engines from being started in the wrong direction, he invented and applied successfully an arrangement known as the "visor," which has been adopted at many other collieries both in this country and abroad. In 1896 he was appointed mechanical engineer to Messrs. Newton, Chambers, and Co., Thorncliffe Iron Works and Collieries, near Sheffield. His death, due to a short severe attack of pneumonia, took place on 10th January 1899, at the age of forty-five. He became a Member of this Institution in 1890.

Thomas Graham Elliott was born at Stockton-on-Tees on 30th March 1847. At an early age his father took him to Manchester, where he was educated at Mr. Ibbotson's academy, and afterwards received his engineering training in his father's works, Ardwick. In 1866 he went as draughtsman to Messrs. Beyer

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Peacock, and Co., Gorton Foundry, and to other works. In 1871 he became head draughtsman to Messrs. Sharp, Stewart, and Co., Atlas Works, Manchester; then for a short time to Messrs. Tangye Brothers, Birmingham; and in 1876 to Messrs. Fairbairn, Naylor, Macpherson, and Co., Wellington Foundry, Leeds. Here two years later he was made manager of the tool department, and continued in this position up to his death, which took place from apoplexy on 17th April 1899 at the age of fifty-two. He invented a self-acting screwing machine, and was engaged in the design and construction of machine-tools of all kinds, especially for the manufacture of armour plates and guns. He became a Member of this Institution in 1882.

Sir JOHN FOWLER, Bart., K.C.M.G., was born on 15th July 1817, at Wadsley Hall, Sheffield. After receiving a good general education, at the age of seventeen he became a pupil of Mr. John Towlerton Leather of Leeds. On leaving his office he was employed for two years by Mr. J. U. Rastrick on the London and Brighton Railway. He then returned to Mr. Leather, for whom he acted as resident engineer on the Stockton and Hartlepool Railway. On its completion he remained two years as engineer and general manager and locomotive superintendent of this and of the Clarence Railway. In 1843 at the age of twenty-six he began work on his own account, and on behalf of Sir John Macneill inspected certain railways near Glasgow, and gave evidence about them before parliamentary committees. In the same year he became the chief engineer of the Sheffield and Lincolnshire, and several other railways projected from Sheffield; these he conducted through parliament, and directed their construction. Subsequently some of the chief works which he carried out, or about which he was consulted, were:—the Oxford Worcester and Wolverhampton, Severn Valley, and London Tilbury and Southend Railways; Liverpool Central Station; Northern and Western Railway of Ireland; lines in New South Wales and India; water works for Sheffield and Glasgow; Metropolitan Inner Circle, St. John's Wood, Hammersmith, Highgate and Midland, Victoria Bridge and Pimlico, and Glasgow Union and City Railways;

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Millwall Docks; Channel Ferry. Of these probably the most novel and the most notable were the Metropolitan Railways and their connections, for which the first act was obtained in 1853, though the works were not commenced till 1860. In 1870, as one of a commission sent to Norway to examine the light railways there in use, with a view to their adoption in India, he reported in favour of 3 feet 6 inches for the Indian gauge, in preference to 2 feet 9 inches recommended by the other commissioners. In 1868, visiting Egypt for his health, he was employed by Ismail Pacha to design irrigation works, to plan a water-way across the Isthmus in competition with the Suez Canal, and to survey a railway to Khartoum. When the British government took control of the country, he placed all his information and experience of Egypt at their disposal; and for this service he was rewarded by being made in 1885 a Knight Commander of St. Michael and St. George. From 1881, in conjunction with his partner Mr. Benjamin Baker, he was occupied with the design and construction of the Forth Bridge; on the completion of which in 1890 a baronetcy was conferred upon him, and Mr. Baker was made a Knight Commander of St. Michael and St. George. Having been elected a Member of the Institution of Civil Engineers in 1844, he became a Member of Council in 1849, a Vice-President in 1859, and President for the two years 1866 and 1867. In his presidential address he sketched a scheme for engineering education, showing a high appreciation of the value of technical training for engineers. He became a Member of the Institution of Mechanical Engineers in 1847, the year of its establishment. His death took place at Bournemouth on 20th November 1898, at the age of eighty-one.

Sir DOUGLAS STRUTT GALTON, K.C.B., was born on 2nd July 1822, at Hadzor House, Droitwich, being the second son of Mr. John Howard Galton; his mother was the daughter of Mr. Joseph Strutt, of Derby, by whom the Derby Arboretum was presented to his townsmen. He first went to a school in Birmingham, and then spent three years in the house of a Swiss pastor near Geneva, where he acquired a knowledge of the French language. He was afterwards educated at Rugby School (Proceedings 1898, page 204); and at the

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age of fifteen entered the Royal Military Academy at Woolwich, having chosen the army as a profession. Here he achieved the distinction of taking the highest place in every subject that was included in the final examination. Receiving his commission in the Royal Engineers in December 1840, he was at once employed under Sir Charles W. Pasley in the destruction of the "Royal George," which had sunk at Spithead in 1782 with such disastrous loss of life, and had ever since proved an obstruction to the navigation of the Solent. The first attempt to blow up the wreck had been made on 29th August 1839, the fifty-seventh anniversary of the vessel's sinking; but it was not until the end of 1840 that it was finally destroyed, by means of explosives fired for the first time by a voltaic battery. From 1843 he served for two or three years in connection with the fortifications at Gibraltar and Malta; and on returning to England in 1846 was engaged for a short time in the Ordnance Survey Office at Southampton. Being appointed upon the Railway Commission in 1847, he became associated with the Board of Trade, where he was first in charge of the statistical department. The breaking down of the railway bridge over the river Dee at Chester led to the appointment of a royal commission to investigate the application of iron to railway structures; he was then Lieutenant Galton, and was appointed secretary to the commission, and conducted the various experiments for them. At the Birmingham meeting of the British Association in 1849 (Report, page xxvii) he assisted Professor Willis in an experimental demonstration of the result arrived at by the investigation. In 1853 he took his commission as captain in the Royal Engineers; and in 1854 he was appointed an inspector of railways. In 1856 he became secretary to the railway department of the Board of Trade, and in this capacity visited the United States officially in the same year, and drew up a report upon American railways. From the experience so acquired he contributed to the Institution of Civil Engineers a paper on railway accidents, showing the bearing which existing legislation had upon them (Proceedings Inst. C.E., 1862, vol. 21, page 363); he pointed out that the deaths due to railway disasters were not abnormal, and deprecated the acquisition of

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railways by the state, as well as undue legislative control. Important improvements which he also urged in the organisation of railway management resulted in advantages of which the value is now fully realised. In 1857, as one of the referees for the main drainage of London, he urged that Barking and Crossness were too near to the metropolis to be suitable sites for outlets into the river; and suggested that the sewage should be taken by means of a tidal channel to Sea Reach, some twenty or twenty-two miles further down the river, whereby a large amount of pumping would be avoided, and the sewage would be diluted on its way down the channel, and would be finally discharged into a large volume of water where it would be innocuous. Subsequent experience has fully confirmed his view that the volume of tidal water at the two higher points in the Thames is too small for thorough dilution of the sewage. When the first submarine telegraph cable laid across the Atlantic in 1857 had failed, and the failure had also occurred of the cable laid in 1859 in the Red Sea as part of a line to India, he was made chairman of the committee of investigation appointed by the government in 1859; the report drawn up by him and published in 1861 formed a valuable guide in all matters of submarine telegraphy; and later he was appointed a member of the consultative committee charged with advising upon all points concerning the laying of the 1865 cable from England to America. Having been a member of Sir Robert Rawlinson's commission formed in 1858, which had reported so unfavourably upon the state of barracks at home and in the Mediterranean station, he was appointed in 1860 Assistant Inspector General of Fortifications, and was entrusted by Lord Herbert with the design and construction of the Herbert Hospital at Woolwich, at that time the largest military hospital in the world, having as many as 650 beds; here he carried into practice his views regarding sanitation, alike for dwelling houses and for barracks. These views he published in three works entitled "Hospital Construction," "Healthy Dwellings," and "Healthy Hospitals." From 1862 to 1870 he was Assistant Under Secretary of State for War; and in 1870 was appointed Director of Public Works and Buildings, at what was then H.M. Board of Works; from the latter post he

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retired in 1875. In 1866 he was appointed a member of a Royal Commission to enquire into the charges made for conveyance on the several railways of Great Britain and Ireland, and to ascertain whether it would be practicable to effect any considerable reduction in the charges, with a due regard to safety, punctuality, and expedition. Their principal report, which he joined in signing, was presented in 1867, and contained numerous recommendations since carried into effect; it also confirmed the opinion he had previously expressed in 1862 as to the inexpediency of the state purchasing or constructing railways. In 1876 he made a second visit to the United States, as one of the judges on this occasion at the Philadelphia Exhibition; and on his return he communicated to the Institution of Civil Engineers (Proceedings 1878, vol. 53, page 28) notes on railway appliances at the exhibition. In 1878 he entered upon that historical series of experiments on the effect of brakes upon railway trains, which have perpetuated his name in the annals of engineering. These experiments were made with the assistance of Mr. Westinghouse on the London Brighton and South Coast Railway, the North Eastern Railway, and the Paris Lyons and Mediterranean Railway; and the results were fully reported and discussed by himself in three papers which he contributed to this Institution (Proceedings 1878, pages 467 and 590; and 1879, page 170); by these were elucidated for the first time the laws of friction in relation to railway brakes. In 1871 he became general secretary of the British Association, and retained the post for twenty-four years, until elected President for 1895–6. In his presidential address at the Ipswich meeting in 1895 (pages 31–4) he strongly urged that the government should establish a National Physical Laboratory, on the principle of the Reichs-Anstalt at Charlottenburg near Berlin. In order to make himself fully acquainted with every detail of that great institution, he paid two visits to Berlin, and prepared a report to present to the British Association. Later he summed up his conclusions in the evidence he gave before the royal commission, which was appointed by the government to report upon the scheme suggested in his address at Ipswich in 1895. The last occasion of his attending a meeting at the Royal Society was in order

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to take his place upon the committee appointed to consider the preliminary steps in connection with the grant promised by the government for the purpose of a National Physical Laboratory. He was made a Companion of the Bath in 1865 when at the War Office, and a Knight Commander of the same order in the Queen's jubilee year 1887. He was made a Commander of the Legion of Honour in 1889, and afterwards a Knight of Grace of the order of St. John of Jerusalem in England; and he held the orders of the Crown of Prussia and of the Medjidie of Egypt. He was elected a Fellow of the Royal Society in 1863, and was also a Member of the Council; and he received the honorary degrees of D.C.L. from Oxford, and of LL.D. from Durham and Montreal. Having been an Associate of the Institution of Civil Engineers from 1850, he was elected an Honorary Member in 1894. He became a Member of this Institution in 1862, and was a Member of Council from 1888, and a Vice-President from 1892. In the arrangements for the new House of the Institution he took an active part throughout, attending numerous committee meetings, and advising upon the many details coming up for decision; and he was present for the last time at the opening meeting in the new building on 9th February 1899. In 1876 he joined in founding the Sanitary Institute, of which he was a Vice-President from its incorporation in 1888; and his last public appearance was as chairman at a meeting of the Institute on 13th February. The subject under consideration was the water supply of London; and he expressed the opinion that it would be prudent for London to be content with the Thames area, and as far as possible to improve the water obtained from this area by storing it and by removing the sources of pollution which exist in the upper valley of the Thames and in the valley of the Lea. On this occasion he spoke of himself as now experiencing the effects of advancing years, and he appeared to be slightly indisposed. Some days later, blood poisoning set in, which resulted in his death on 10th March 1899 in the seventy-seventh year of his age. He was a justice of the peace for Worcestershire, and also a county councillor. The interment took place at Hadzor Church, adjoining his birthplace. A memorial

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service was held in St. Peter's Church, Eaton Square, London, at which an address was delivered by the Dean of Gloucester, Dr. H. Donald M. Spence, appreciating from personal knowledge the practical importance of his life's work to the health, happiness, and welfare of his fellow-countrymen, and of mankind at large.

JEREMIAH HEAD was born at Ipswich on 11th July 1835. After receiving his early education at home, in a private school at Ipswich, and at Tulketh Hall near Preston, at the age of sixteen he was articled in 1852 for five years in the works of Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, where he served three years and a half in the pattern-making, fitting, and erecting shops, and the remaining year and a half in the drawing office. During the latter part of his time and for a year subsequently he was engaged in the designing and erection of two compound mill engines; one of these, for Messrs. Henry Pease and Co.'s Priestgate Woollen Mills at Darlington, was fitted for the first time with a true parabolic governor in 1856, to which he subsequently added an air cataract to prevent hunting; the other engine, for Messrs. Annandale and Sons' Paper Mills at Shotley Bridge, was also fitted with a similar governor, of which there were several later examples in Messrs. R. Stephenson and Co.'s works. A simplified arrangement with crossed arms, forming a closely approximate parabolic governor, was subsequently devised by him for a large single-cylinder horizontal engine driving two plate-mills at the Newport Rolling Mills, Middlesbrough; and nine others were also employed at the same works. Of these governors and of their successful working he gave a description to the first Middlesbrough Meeting of the Institution (Proceedings 1871, pages 213–23), for which he acted as honorary local secretary. For two years 1857–9 he was employed under Mr. Robert Stephenson and Mr. G. H. Phipps in the reconstruction of Rowland Burdon's celebrated cast-iron bridge, originally erected in 1796 over the river Wear for connecting Sunderland and Monkwearmouth; it consisted of a single arch, forming an arc of a circle of 237 feet span and 33 feet rise, with a clear height of 99 feet above low water (Proceedings 1858, page 261). The Royal Agricultural Society

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having offered a prize for a steam plough, he was entrusted with the work of developing into practical form the idea conceived by Mr. John Fowler of Leeds; with the result that the prize was won at the Chester Show in 1858 by the plough made under his direction at Messrs. Stephenson's works, whence fifteen more of the same kind were afterwards turned out. Subsequently he went for a short time to Messrs. Kitson and Co., Airedale Foundry, Leeds; and then became manager of the Steam Plough Works of Messrs. John Fowler and Co. in Leeds until 1860; and besides constructing nearly a score of steam ploughs, he devised a plan of signalling by lamps to facilitate steam-ploughing at night. As agent for the firm he next spent some time at Swindon, demonstrating the practical capabilities of the steam-ploughing tackle upon farms in Wiltshire. In the spring of 1863 he joined Mr. Theodore Fox in founding the firm of Fox, Head, and Co., and erected the Newport Rolling Mills, Middlesbrough, for the manufacture of iron plates. Here they employed 600 men, and produced 400 tons of finished iron per week, using machinery which dealt with larger masses of wrought-iron than had hitherto been worked. For over twenty years he devoted himself to the details of this business, and carried into practice a plan of profit-sharing with his workmen, which was so far successful that no labour disputes arose between them even during a disturbed period. In other ways also he sought to improve the condition of the workmen; and largely owing to his initiation Middlesbrough was the first town in England to apply for the establishment of a school board after the passing of the act. Of this board he was for several years an active member. With the object of improving the industries of the district and increasing its prosperity, he originated in 1864 the Cleveland Institution of Engineers, whose interests he served for three years as honorary secretary, and afterwards for three years as President, performing during the whole of the time much work of great benefit to the district. In 1885 the firm of Messrs. Fox, Head, and Co. was dissolved, and he devoted his time and energy to wider interests as a consulting engineer in Cleveland. In 1888 he laid out the Bowesfield Iron Works at Stockton-on-Tees, and in 1891 the New British Iron Works at Corngreaves near Birmingham. In

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January 1894 he moved his offices from Middlesbrough to Westminster, where he thenceforth practised. Several times he visited iron works in Norway; and in Spain he examined manganese mines near Santander, coal mines near Oviedo, and iron ore deposits near Bilbao and Santander. To the United States he made ten visits, bringing back thence many valuable suggestions for practical improvements in engineering industries in this country. The results of his observations he freely communicated to the leading professional societies, in papers on the iron ore deposits in Scandinavia, on American and English steel manufacture, and other subjects; his latest contribution was a paper prepared in conjunction with his son upon the Lake Superior iron ore mines, which was presented to the Institution of Civil Engineers on 14th February 1899. He acted as consulting engineer in this country for the Otis Steel Works in Ohio, and for the Alberta Irrigation in Western Canada. In 1894 he visited Salt Lake City, and reported upon a Mormon railroad; and also upon a proposed railroad from the iron works in Alabama to the Tennessee River. As an arbitrator he settled many questions between employers and workmen, including differences at Messrs. Bolckow Vaughan and Co.'s Works and at the Barrow Steel Works. In 1896 he reported for the Indian government upon the iron ore deposits at Salem in the Madras presidency, arriving at the conclusion that it would be impracticable to smelt the ores on the spot in the absence of suitable fuel and in the face of the competition of English iron delivered there. He became a Member of this Institution in 1859, and again after an interval in 1869; a Member of Council in 1874; and a Vice-President in 1880. At a season of sudden emergency, with characteristic self-forgetful readiness, he complied with the unexpected request of the Council to accept the presidency; and by the admirable manner in which he bore the anxieties and fulfilled all the duties of President during the two years 1885–6, he greatly enhanced the dignity and stability of the Institution, and won the warmest esteem of the Members. In 1893 he obligingly took upon himself as a Past-President the organization of the arrangements for the second Summer Meeting in Middlesbrough, for which he personally procured and arranged the extensive statistics

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furnished to the Members in the descriptions of the numerous works they then visited. On that occasion also, as well as in his two Presidential addresses, he enriched the Institution Proceedings with a store of information, interspersed with suggestions affording material for reflection. The paper he then read, on recent developments in the Cleveland iron and steel industries (Proceedings 1893, page 224), gave the best description that has yet been written of that remarkable district. He was a Member of the Institution of Civil Engineers from 1875; and of the Iron and Steel Institute from 1869, the year of its formation. In 1893 he was President of the mechanical section of the British Association at the Nottingham meeting. From 1894 he was a Member of Council of the Federated Institution of Mining Engineers. Having considerably overtaxed his strength, he went at the beginning of the present year to Bournemouth for a short rest, and afterwards to Hastings, where he appeared to be progressing favourably towards speedy re-establishment of health, when his death occurred suddenly from congestion of the brain on 10th March 1899 at the age of sixty-three.

PETER ROTHWELL JACKSON was born in Liverpool on 22nd July 1813; but shortly afterwards his parents went to live in Bolton, where he commenced work at an early age, serving his apprenticeship as an engineer with the firm of Rothwell, Hick, and Rothwell, at the Union Foundry, which was then one of the largest foundries in Lancashire, affording employment to about 400 men. During his apprenticeship he made a foot lathe, to which amongst other devices he fitted two cylindrical brushes for cleaning boots, this being probably the earliest attempt at shoe-cleaning by machinery. He also invented an improved method of cutting screw-threads of various pitches on steel taps and other short screws, at that time a somewhat difficult operation. Later he took out a patent, the first after Bramah's, for improvements in hydraulic presses, his attention having been drawn to this subject by the frequent bursting of the press cylinders at the Union Foundry; although the thickness of metal in them had been increased to as much as 8 inches, they frequently gave way. He therefore adopted the bold expedient of

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reducing the cylinder walls from 8 inches to only 7-8ths inch thickness, extending the main tension-bolts of the press so as to permit of the cylinder being supported from below, and securing the necessary circumferential strength by hooping the cylinder with three sets of wrought-iron hoops carefully shrunk on, after the manner subsequently adopted by Sir William Armstrong in the manufacture of heavy ordnance. He was indeed anxious to apply this method to gun-making, but was dissuaded from doing so by his friend, Mr. John George Bodmer, who, while entirely approving of the plan, represented the difficulties he had himself experienced in trying to introduce novel ideas to government officials. The press cylinders thus strengthened proved highly successful; and the hydraulic presses as made by him continued in use until cast-steel hydraulic cylinders could be obtained at a reasonable cost. In consequence of a dissolution of partnership in the firm, the works management at the Union Foundry devolved chiefly on himself when only about nineteen years of age and still in his apprenticeship. Although this position carried with it far too much responsibility for his years, it no doubt developed his capabilities, and proved most useful to him in after life. When about twenty-two years old he left Messrs. Rothwells, and with his two brothers purchased the Wharf Foundry in Bolton. Being a sound mechanic and a most patient designer, he spared no pains to give the best possible form to any machine he had in hand, whether the main idea had originated with himself or with another. The ultimate success of Mr. Bodmer's plan for rolling railway-wheel tires was chiefly owing to the thought and pains Mr. Jackson bestowed upon working it out practically; he constructed the mill in such a way that it rolled the tires so exactly as to enable many of them to be shrunk on their wheels and put to work without either boring or turning. Even now the Jackson tire-mill is considered by competent judges to be capable of turning out better work than any other. The same thought and care characterised the working out in all their details and accessories of his own inventions, in 1848 and 1854 respectively, of a hydraulic starting apparatus and of a wheel-moulding machine for toothed gearing. Of the former he gave a description to this Institution in 1848 (Proceedings

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April, page 12), when he had had it at work for two or three months. The moulding of toothed wheels by machinery has since become practically universal; and so perfectly were all the conditions met by his method that several of his earlier machines are still in successful operation, notwithstanding the adverse conditions under which they work, owing to the dust and sand inseparable from an iron foundry. The first of these moulding machines he described to the Institution in 1855 (Proceedings, page 41), with particulars of the work it had done during the eight or nine months it had been in operation since starting. Both the rolling of the tires and the making of the hydraulic starting apparatus and of the toothed wheels were carried out by him at the Salford Rolling Mills, Manchester, established by him in 1840 for the manufacture of railway tires, and subsequently developed into a large iron and steel foundry, and in recent years into electrical engineering works. He was one of the original Members of this Institution from its formation in 1847; and he used often to recall with interest the fact that he had attended the first meeting, held in Birmingham on Wednesday 27th January 1847, under the presidency of George Stephenson, at which the Institution was established (Proceedings 1897, pages 259–260). His death took place at his residence, Blackbrooke, Skenfrith, Monmouthshire, on 8th February 1899, in the eighty-sixth year of his age.

WILLIAM LAIRD was born at Birkenhead on 11th April 1831, being the eldest son of Mr. John Laird, M.P. After receiving his education in Liverpool and at Harrow, he was taken into his father's office in the iron shipbuilding works of Messrs. William Laird and Son. Devoting himself to mastering the details of scientific shipbuilding, he early became the head of the drawing department, where he had the complete control of the work of designing, and the revision of all contracts for work undertaken by the firm. When this department was taken over by his younger brother Henry Hyndman (Proceedings 1893, page 205), he still devoted much time to it himself. On 1st January 1860 he was admitted a member of the firm, along with his brother John, and the title was changed to

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John Laird, Sons, and Co. At the end of 1861 his father retired from the firm, and in the middle of 1862 Mr. Henry Hyndman Laird was admitted into what then became the firm of Messrs. Laird Brothers, of which Mr. William Laird was the senior partner. Among the famous productions of the works under his guidance were the ironclad battle-ship "Agincourt" in 1865, followed by the "Vanguard," the "Britannia," and many other vessels; then in 1880 three channel steamers for the London and North Western Railway; in 1886 the "Rattle-snake" torpedo gunboat, the first of a long line of high-speed boats; in 1889 the "Columbia," the largest merchantman ever constructed on the Mersey, owned by the Hamburg American Company; and recently the first-class battle-ships "Royal Oak" and "Mars," and a fleet of 30-knot torpedo destroyers, as well as one boat of 33 knots; also the "Cephalonia," the "Westernland," and the "Noordland"; the battle-ship "Glory," of 12,500 tons, at present in the building dock; and Mr. Vanderbilt's floating palace "Valiant." For the Irish mail service between Kingstown and Holyhead the steamers "Ulster," "Munster," and "Connaught," were built in 1860, of which he was the actual designer; then in 1885 the royal mail steamer "Ireland," probably the fastest paddle-boat in the world; and in 1896 four twin-screw steamers, "Ulster," "Leinster," "Munster," and "Connaught," having a speed of nearly 24 knots, for the accelerated Irish mail service, to replace the three built in 1860. Since the death of Mr. John Laird on 25th January 1898, the whole burden of the firm was principally borne by Mr. William Laird, who continued to attend to business up to a few days before his death, which occurred on 7th February 1899, in the sixty-eighth year of his age. He became a Member of this Institution in 1872, and was a Member of Council from 1887. He was also a Member of the Institution of Naval Architects, and a Member of their Council. From the incorporation of Birkenhead in 1877 he had a seat on the Town Council; and was Mayor for the three years 1880–1–2, and again for 1886. In 1875 he was appointed a justice of the peace for the county of Cheshire; and when the borough bench was formed in 1878, he became one of the first magistrates of Birkenhead.

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JOHN WILLIAM NAYLOR was born on 1st August 1827, at Folly, Beeston Hill, Leeds, where his family were well known as cloth manufacturers. In 1843 he went to work in the old Wellington Foundry of Sir Peter Fairbairn, maker of flax and woollen machinery. In 1863, two years after the death of Sir Peter Fairbairn, he was taken into partnership by his son Sir Andrew Fairbairn, along with Mr. T. S. Kennedy (Proceedings 1894, page 598); and from 1883 he was managing director of the concern. He was also a director of the Lancashire and Yorkshire Railway, chairman of the income-tax commissioners in the Leeds district, and a justice of the peace for Leeds and for the West Riding of Yorkshire. He resided at Chapel Allerton, near Leeds; and his death took place suddenly while on a visit to London, on 4th June 1899, in the seventy-second year of his age. He became a Member of this Institution in 1861, and was also a Member of the Iron and Steel Institute.

EXHAM PHILLIPS was born in Cork in 1847. After receiving his early education there, he served an apprenticeship from 1859 to 1866 in the engineering works of Messrs. Richard Perrott and Sons, Cork. He then matriculated in the department of engineering at the Queen's College, Cork, of the Royal Irish University, and studied in the course from 1867 to 1869. From 1869 to 1885 he was manager of the Neville Iron Works of Messrs. Walker and Emly, Newcastle-on-Tyne. In 1886 he became manager of the drawing office of Messrs. Thomas Bradford and Co., Crescent Iron Works, Salford, Manchester. His death occurred on 27th March 1899 in the fifty-second year of his age. He became an Associate Member of this Institution in 1895.

WILLIAM ROBERTSON was born at Newfaulds in the parish of Lochwinnoch, Renfrewshire, on 23rd February 1833, his father being a farmer. After being educated at the parish grammar school, he served an apprenticeship for five years 1852–57 in the Eglinton Engine Works of Messrs. A. and W. Smith in Glasgow; and then worked as a journeyman in 1858 and 1859 with Messrs. Caird and Co.,

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engineers and shipbuilders, Greenock. At the end of 1859 he went under an engagement to Soehia near Smyrna in Asia Minor, to erect sugar machinery. In 1863 he went to Shanghai, China, and was engaged as chief engineer in steamers running on the coasts of China and Japan. In 1867 he became a partner in the firm of Messrs. Boyd and Co., engineers and shipbuilders at Shanghai; and was principal in starting works for the firm in Nagasaki and Yokohama, Japan, on behalf of the Japanese government. In 1892 he returned to England, and resided principally at Hampstead, London, where his death took place on 8th November 1898 in the sixty-sixth year of his age. He became a Member of this Institution in 1879.

FREDERICK RYLAND was born in Birmingham on 28th March 1845, being the eldest son of Mr. William Ryland, who for many years was manager of Messrs. Elkington and Co.'s electro-plating works. On leaving school he was apprenticed in 1861 to the engineering firm of Messrs. May and Mountain, Suffolk Works, Birmingham; from whom in 1866 he went as engineering assistant to the works of Messrs. Archibald Kenrick and Sons, hardware manufacturers, Spon Lane, West Bromwich. In 1883, when this business was formed into a company, he became a director. He was a magistrate of West Bromwich, and took an active interest in the welfare of the educational and charitable institutions of the town. His death took place on 11th February 1899 at the age of fifty-three, after four months' illness resulting from an attack of influenza. He became a Graduate of this Institution in 1866, and a Member in 1869.

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1899. No. 2.

THE INSTITUTION OF MECHANICAL ENGINEERS.

PROCEEDINGS.

APRIL,

1899.

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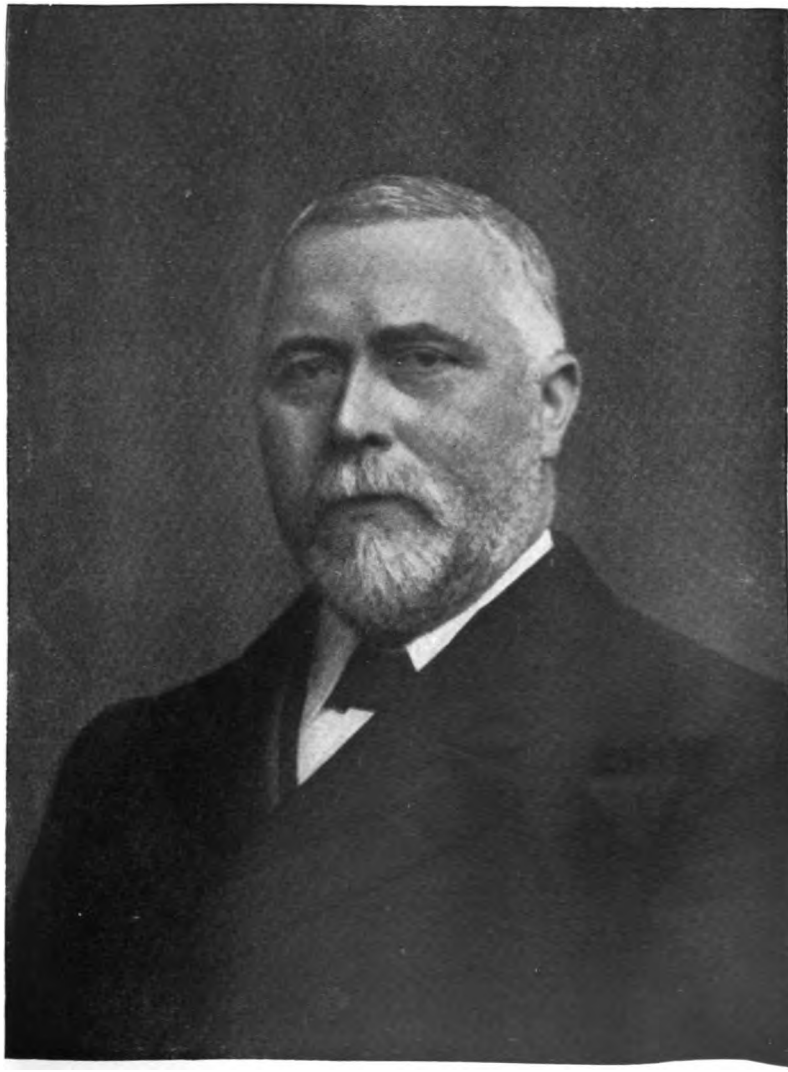

Elliott & Fry.

P. A. White
March 1899

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The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1899.

The Spring Meeting was held in the House of the Institution, St. James's Park, London, on Thursday, 27th April 1899, at Half-past Seven o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that H.R.H. the Duke of York had accepted the invitation of the Council to become an Honorary Member of the Institution.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following one hundred and four candidates were found to be duly elected:—

MEMBERS.

Appleby, George William,	Hong Kong.
Atherton, Thomas,	Warrington.
Awdry, Walter Llewellyn,	Birmingham.
Bayley, George Ridley,	Liverpool.
Beaumont, Roberts,	Leeds.
Byrne, John Joseph,	Athy.
Clark, Henry,	Stockton-on-Tees.

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CRAVEN, JOHN ALFRED,	Sheffield.
DAN, TAKUMA,	Tokyo.
DEAS, JAMES,	Warrington.
DREW, ALEXANDER,	Edinburgh.
DRUMMOND, WALTER,	Glasgow.
DURSTON, SIR ALBERT JOHN, K.C.B., R.N.,	London.
ELFORD, ERNEST JOHN,	Portland.
FORD, THOMAS WHARTON,	London.
FORD-MOORE, ARTHUR PILCHER,	London.
FRASER, PATRICK,	Arbroath.
HAMMOND, ROBERT,	London.
HOLMES, JOHN HENRY,	Newcastle-on-Tyne.
HOSGOOD, OCTAVIOUS SIDNEY,	Cardiff.
HUGHES, GEORGE,	Manchester.
HUNTER, GEORGE LEWIS,	Cardiff.
JAMES, HERBERT HOLLAND,	London.
KEKEWICH, GEORGE ORMOND,	London.
KILGOUR, MARTIN HAMILTON,	Cheltenham.
KING, JOHN JAMES,	Nottingham.
KIRKALDY, WILLIAM GEORGE,	London.
MACDONALD, JOHN,	Glasgow.
MASTRANTONIS, PANAYOTIS,	Piraeus.
NISBET, WILLIAM HOLMES,	Brisbane.
OSBORNE, THOMAS PETER,	Derby.
PARKER, THOMAS HUGH,	Wolverhampton.
PEET, JAMES,	Trinidad.
QUIN, ROBERT CORNELIUS,	Blackpool.
RIDE, SAMUEL,	Manchester.
ROBINS, GEORGE MEAD,	Sutton, Surrey.
SANDEMAN, EDWARD,	Plymouth.
SHEPHERD, RICHARD LILLINGTON,	Queenstown, Tasmania.
SMETHURST, WILLIAM,	Manchester.
SURTEES, HENRY WARDALE,	Derby.
UNSWORTH, HERBERT GEORGE,	Swansea.
URIE, WILLIAM MONTGOMERIE,	Glasgow.
WADDINGTON, RICHARD,	London.

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Williams, William Henry,	Swindon.
Wilson, Charles Louis Napoleon,	Bilston.
Wilson, William Hope,	Glasgow.
Yates, Joseph,	Manchester.
Yates, Walter,	Manchester.

ASSOCIATE MEMBERS.

Ambrose, Sewell Powis,	Manchester.
Arnold, Arnold Attwood,	Ipswich.
Baber, Samuel Ernest,	Bristol.
Backhouse, John,	London.
Bateman, Arthur Henry,	London.
Bettig, Robert,	Lille.
Beves, Norman Ellison,	Edinburgh.
Cannell, William,	Coventry.
Chapman, Samuel,	Manchester.
Clarke, Arthur Laver,	Maldon.
Dodridge, Frederick,	Devonport.
Dutch, Ernest,	Wigan.
Fairley, Frank,	London.
Flint, Leonard Robert,	London.
Fox, Henry Shoolbred,	London.
Fulcher, George Chambers,	London.
Gibbins, John Ernest,	Sheffield.
Girvan, William,	Sandakan, B.N. Borneo.
Hadley, William Pearce Holbrow,	Silchar.
Hepworth-Collins, Walter,	Dublin.
Hollingsworth, Allen Alexander,	Sheffield.
Holmes, Harry,	Birmingham.
Horsnaill, William Owen,	Manchester.
Hunt, Henry,	London.
McFerran, Howard A.,	London.
Nettlefold, Godfrey,	Birmingham.
Oates, Arthur Job,	Darlaston.
Oswald, George Herbert,	Newport, Mon.

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PETTER, PERCIVAL WADDAMS,	Yeovil.
PRICE, WILLIAM FREDERICK,	Liverpool.
RAPSON, JOSIAH TREVOR,	London.
RICHARDSON, JOHN ROBERT,	Lincoln.
ROBERTS, BASIL OWEN,	King's Lynn.
ROSEVERE, GERALD RHODES,	Birmingham.
SCOTT, ROBERT,	Klipdam, S. Africa.
SHAWCROSS, GEORGE NUTTALL,	Bolton.
SOMERVILLE, FREDERICK HERBERT,	Chelmsford.
TESTER, WILLIAM ANDREWS,	London.
TRUNCHION, WILLIAM THOMAS FAWDON,	Bedford.
WALKER, WILLIAM PETO,	London.
WHEELER, GEORGE UZZIAH,	Birmingham.
WHITEHEAD, JAMES PETER,	Manchester.
WILLIAMS, HAL,	London.
WILLIAMSON, EDWARD,	London.

ASSOCIATE.

DADGE, NELSON,	Edinburgh.

GRADUATES.

DAWSON, JOHN EDWARD,	Bradford.
DODGE, SAMUEL BRICKHILL,	Hove.
EDWARDS, WILLIAM BERNARD,	Birmingham.
GOODMAN, FRANK ADOLPHUS,	Torquay.
MARSDEN, ALFRED,	Leyland, Lancs.
MAYO, WILLIAM HENRY,	Malvern.
O'BRIEN, HENRY EOGHAN,	Bolton.
PROSSER, ROBERT WALTER OSTELL,	Blaydon-on-Tyne.
SANDERSON, HERBERT WILLIAM,	Nottingham.
TAYLOR, FRANK COSTON,	Bolton.
WRAY, ROMULUS PAUL,	London.

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The PRESIDENT further announced that the following six Transferences had been made by the Council since the last General Meeting:—

ASSOCIATE MEMBERS TO MEMBERS.

BRADLEY, JAMES WILLIAM, . . .	Wolverhampton.
DAWSON, PHILIP, ...	London.
MANSFIELD, EDWIN ALBERT, . . .	London.
RICHMOND, WILLIAM FREDERICK, . .	Longton, Staffs.
ROOTS, JAMES D., ...	London.

GRADUATE TO ASSOCIATE MEMBER.

JONES, ARTHUR DANSEY, . . .	Manchester.

The PRESIDENT said that at the previous meeting the Institution had been honoured with the presence for the last time of their late Vice-President, Sir Douglas Galton. Shortly after the meeting he had been taken seriously ill, and his death had occurred just seven weeks ago, to the great regret not only of this Institution but of many other societies also. The vacancy thereby occurring had been supplied by the Council, in conformity with the articles of association, by the appointment of Mr. Arthur Tannett Walker, of Leeds, as a Vice-President for the present year; and the vacancy consequently created on the Council had been filled by the appointment of Mr. Henry Lea, of Birmingham, as a Member of Council for the present year, his name being the next highest in the voting for the election at the Annual General Meeting. Agreeably with the articles of association, both these gentlemen would retire at the next Annual General Meeting, and would be eligible for re-election.

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The PRESIDENT then delivered his Inaugural Address on "The Connection between Mechanical Engineering and Modern Shipbuilding."

The Meeting was then adjourned at ten minutes past Nine o'clock to the following evening. The attendance was 170 Members and 68 Visitors.

The ADJOURNED MEETING was held in the House of the Institution, St. James's Park, London, on Friday, 28th April 1899, at Half-past Seven o'clock p.m.; SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The following Paper was read and discussed :—

"Evaporative Condensers"; by Mr. HARRY G. V. OLDHAM, *Associate Member*, of London.

The Meeting then terminated at a Quarter before Ten o'clock. The attendance was 103 Members and 68 Visitors.

ANNUAL DINNER.

The ANNUAL DINNER of the Institution was held at the Hotel Cecil, Strand, on Wednesday evening, 26th April 1899, and was largely attended by the Members and their friends, the company numbering upwards of three hundred. The President occupied the chair; and the following Guests accepted the invitations sent to them, although those to whom an asterisk * is prefixed were unavoidably prevented at the last from being present. The Right Hon. George J. Goschen, M.P., D.C.L., LL.D., F.R.S., First Lord of

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the Admiralty; the Right Hon. the Earl of Hopetoun, G.C.M.G., P.C., Lord Chamberlain; the Right Hon. Rear-Admiral Lord Charles Beresford, C.B., M.P.; the Hon. J. C. Burns, President of the Chamber of Shipping; Sir Thomas Sutherland, G.C.M.G., M.P., LL.D., Chairman of the Peninsular and Oriental Steam Navigation Co.; Vice-Admiral Sir Frederick G. D. Bedford, K.C.B., Lord of the Admiralty; Lieut.-General Sir Henry Brackenbury, K.C.B., K.C.S.I., R.A., Director-General of Ordnance; the *Right Hon. Sir Francis H. Jeune, President of the Probate, Divorce, and Admiralty Division; the *Hon. Sir Walter G. F. Phillimore, Bart., Justice of the Queen's Bench Division; Rear-Admiral Arthur K. Wilson, C.B., V.C., Controller of the Navy; the Hon. Sir George Shenton, President of the Legislative Council of Western Australia; Sir William C. Roberts-Austen, K.C.B., D.C.L., F.R.S., Honorary Life Member; *Monsieur D. Dumont, President of the Société des Ingénieurs Civils de France; Sir Albert John Durston, K.C.B., Engineer-in-Chief of the Royal Navy; Major-General J. B. Sterling; *Mr. W. G. Ellison Macartney, M.P., Financial Secretary to the Admiralty; *Sir John Jackson, F.R.S.E.; Captain Fiéron, Naval Attaché to the French Embassy; Colonel Edmund Bainbridge, C.B., Chief Superintendent of the Ordnance Factories; Commander Kawashima, Naval Attaché to the Japanese Embassy; the *Worshipful the Mayor of Devonport, Alderman W. Hornbrook; *Mr. J. A. Travers, Prime Warden of the Fishmongers' Company; *Captain Wilmot H. Fawkes, R.N.; *Mr. T. H. Ismay, Chairman of the White Star Line of Steamships; Professor W. Cawthorne Unwin, F.R.S., Honorary Life Member; Professor W. F. M. Goss, Purdue University, Lafayette, Indiana, U.S.A.; Professor D. E. Hughes, F.R.S.; *Mr. Edwin Tate; Mr. Quintin Hogg, The Polytechnic.

Mr. W. H. Preece, C.B., F.R.S., President of the Institution of Civil Engineers; Mr. Edward P. Martin, President of the Iron and Steel Institute; Mr. Joseph W. Swan, F.R.S., President of the Institution of Electrical Engineers; *Mr. William Armstrong, President of the North of England Institute of Mining and Mechanical Engineers; Mr. Charles D. Abel, President of the Chartered Institute of Patent Agents; *Dr. John Inglis, President of

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the Institute of Marine Engineers; Dr. J. H. T. Tudsbery, Secretary of the Institution of Civil Engineers.

Mr. Alfred Bache; Mr. James S. Beale, Honorary Solicitor; *Mr. William Gowland; *Mr. Harry Lee Millar, Honorary Treasurer; Mr. Harry G. V. Oldham; *Mr. William Powrie; Mr. Basil Slade, Architect; Mr. C. J. Wilson, F.I.C.

The President was supported by the following officers of the Institution:—*Past-Presidents*, Sir Lowthian Bell, Bart., F.R.S.; Sir Edward H. Carbutt, Bart.; Mr. Samuel W. Johnson; Mr. E. Windsor Richards; and Mr. Percy G. B. Westmacott. *Vice-Presidents*, Mr. Arthur Keen; Mr. Edward P. Martin; Mr. T. Hurry Riches; and Mr. A. Tannett Walker. *Members of Council*, Mr. John A. F. Aspinall; Mr. Henry Chapman; Mr. Henry Davey; Mr. Bryan Donkin; Mr. H. Graham Harris; Mr. Henry Lea; Mr. J. G. Mair-Rumley; and the Right Hon. W. J. Pirrie.

After proposing the usual loyal toasts, the President announced that H.R.H. the Duke of York had accepted the nomination of the Council as an Honorary Member of the Institution. Sir Edward H. Carbutt, Bart., Past-President, proposed the toast of "The Navy, Army, and Reserve Forces," which was acknowledged by the Right Hon. George J. Goschen, M.P., D.C.L., LL.D., F.R.S., First Lord of the Admiralty, who, in responding for the Navy, dwelt upon the close connection of mechanical engineers with naval architecture and marine engineering. They were invisible contributors to many of the triumphs of civil engineers and naval architects; and any one descending into the interior of a warship would see at a glance to how vast an extent mechanical engineers had contributed to the construction of the whole. Such a vessel might indeed appropriately be called a museum of mechanical engineering. Air, fire, water, and electricity had been subdued by mechanical engineers for the accomplishment of their work; and they were still ousting from their present domain of activity other forces besides human labour. But human activity they could not entirely succeed in superseding in a man-of-war, where trained intelligence was now more than ever required to put their appliances into efficient operation. Such training schools as the "Vernon" and the "Defiance" were sending

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forth naval officers who, he might venture to say, were themselves to a certain extent mechanical engineers. The education of naval officers had now been in a great degree modified through the Institutions of Mechanical Engineers, Naval Architects, and Electrical Engineers. The whole navy had thereby been raised intellectually, and had become habituated to higher, or at any rate more complicated, duties than those which in former days had to be performed. Though some might have their misgivings whether in the stress of storm or the heat of battle the mechanical complications of a warship could be correctly manipulated, he was satisfied that the coolness of the present naval officers could be confidently relied upon, because of their practical knowledge of the mechanism, and their readiness of resource if any part of it should get out of order. In the future advances effected by mechanical engineers he trusted there would be simplicity as well as complexity, because he feared lest in a man-of-war greater complexity might hardly be compatible with the efficient performance of the duties to be discharged. Lieut.-General Sir Henry Brackenbury, K.C.B., K.C.S.I., R.A., Director-General of Ordnance, replied for the Army and Reserve Forces. The toast of "Our Guests," proposed by the President, was acknowledged by Sir Thomas Sutherland, G.C.M.G., M.P., LL.D., Chairman of the Peninsular and Oriental Steam Navigation Co.; by the Hon. Sir George Shenton, President of the Legislative Council of Western Australia; and by Professor W. F. M. Goss, of Purdue University, Lafayette, Indiana, U.S.A. Mr. E. Windsor Richards, Past-President, proposed the toast of "Kindred Societies," which was acknowledged by Mr. W. H. Preece, C.B., F.R.S., President of the Institution of Civil Engineers. The remaining toast of "The Institution of Mechanical Engineers" was proposed by the Right Hon. Rear-Admiral Lord Charles Beresford, C.B., M.P., who suggested that the position of engineers in the fleet should be officially enquired into; for his own part he should like to see both the Director of Naval Construction and the Engineer-in-Chief occupy the rank of Rear-Admiral. The toast was acknowledged by the President.

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ADDRESS BY THE PRESIDENT,

Sir WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S.

THE CONNECTION BETWEEN MECHANICAL ENGINEERING AND MODERN SHIPBUILDING.

For the first time the Presidential Chair of this Institution is occupied by a Naval Architect. Marine engineering has been worthily represented by the late Mr. John Penn, who served as President for four years, 1858–59 and 1867–68. Mr. Robert Napier, distinguished both as a shipbuilder and an engineer, was elected President three years in succession, 1863–64–65. After an interval of thirty-three years you have conferred upon another representative of the shipbuilding industry the honour of serving the Institution as its President, at a notable period of its history. Entering its new and permanent home, the Institution must in many ways make new departures, if its highest efficiency and usefulness are to be realised. Those charged with the conduct of its affairs consequently have the greater responsibility. Speaking on behalf of the Council, I can assure you that no effort will be spared to advance the best interests of the Institution, and to provide for all classes of its members.

Mechanical engineering has intimate relations with all other branches of engineering. With none has it been more closely associated than with shipbuilding in recent times, and upon none has its influence been greater or more beneficial. The growth of our shipbuilding industry and the marvellous development of our mercantile marine during the last forty years are matters of common knowledge. The causes which have contributed to this supremacy are not so well understood, and the part which mechanical engineering has played is not generally appreciated. In this address my principal aim will be to indicate the directions in which shipbuilding and the working of ships have been influenced by mechanical engineering.

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The total tonnage of steamships for the whole world is about 19,500,000 tons, and of sailing ships about 7,050,000 tons. The United Kingdom owns 54 per cent. of the total steamship tonnage, and 29 per cent. of the sailing ship tonnage. The British Empire owns 57 per cent. of the steamship tonnage, and over 35 per cent. of the sailing ship tonnage. Last year (1898) we launched more than a million tons of shipping which were registered in British ports as additions to our fleet.

British shipbuilding attained its highest production last year, when, according to the valuable returns issued by Lloyd's Register, the following ships were launched in the United Kingdom:— 761 merchant ships of 1,367,570 tons (gross register) and 41 warships of 191,555 tons (displacement). British Colonies launched 70 ships of 25,000 tons. During the same period all other countries launched 509 ships of 676,000 tons. The United States had an output of 170 ships and 241,000 tons; Germany 114 ships of 168,400 tons; France 57 ships of nearly 102,000 tons. The individual production of either the Glasgow, Newcastle, or Sunderland district exceeded the total output of the United States. Belfast alone launched 16 ships of nearly 120,000 tons, and the Hartlepools and Whitby 44 ships of nearly 126,000 tons. Of the total tonnage set afloat in 1898, 70 per cent. was launched by the British Empire.

The salient facts in these returns, apart from the magnitude of the production, are the practical disappearance of sailing ships from the list of vessels launched in the United Kingdom; the almost universal employment of steel instead of iron; and the continued increase in the average size and tonnage of ships. Only 17 sailing ships were launched, averaging about 250 tons; as against 744 merchant steamers, averaging over 1,800 tons, and 41 warships, averaging nearly 4,700 tons (displacement). In 1860 the British mercantile marine included 8,242 sailing vessels of over 3,000,000 tons (net register), as against 527 steamers of 307,000 tons. At the end of 1897 the figures were 1,604 sailing ships of less than 2,000,000 tons, and 3,715 steamers of nearly 5,756,000 tons (net register). As it is estimated that the comparative efficiency of steam to sailing tonnage

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is at least as three to one, it follows that, whereas the total steam tonnage of 1860 was equivalent to less than one-third of the sailing tonnage, at the end of 1897 it was equivalent to nearly nine times the sailing tonnage on the British register.

The use of iron for shipbuilding may be roughly stated to have commenced about sixty years ago. In 1850 out of 133,700 tons of new shipping added to the British register only 12,800 tons were iron and over 120,000 tons were wood. In 1860 out of 212,000 tons 64,700 tons were in iron ships. In 1868 out of 369,000 tons 208,000 tons were iron; in 1880 out of 404,000 tons 384,000 tons were iron and 20,000 tons wood. Steel was used to a very limited extent prior to 1875. In 1878 only 4,500 tons of steel shipping were classed at Lloyd's, and in 1881 41,400 tons. The total tonnage of steel ships in 1881 was less than 6 per cent. of the aggregate tonnage of iron and steel ships. In 1892 steel had reached 98 per cent.; and 99 per cent. of the new tonnage launched in 1898 was steel. Iron is now used only for trawlers and small vessels of less than 250 tons.

With the change from sail to steam and from iron to steel has come a great increase in the average size of sea-going ships; and in recent years the construction of a considerable number of very large vessels, designed either for high-speed passenger service, or for the conveyance of enormous cargoes at moderate speeds. The "Oceanic" of the White Star Line is the latest representative of the former class; and no less than six steamers of the latter class, ranging from 8,000 to 12,000 tons, were launched in 1898 in the United Kingdom.

In all these changes, as will be shown hereafter, mechanical engineering has played an important part. A close alliance between the shipbuilder and the mechanical engineer has been essential to success. British supremacy in shipowning and shipbuilding is not an accident. It has been won by the enterprise of shipowners, and by the readiness of shipbuilders to initiate or adopt improvements in materials and methods of construction, in types of ship, and in character of equipment. Forty years of continuous effort on these lines of progress have produced a mercantile marine which has been

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valued by a high authority at 250 millions sterling, while its annual earnings are estimated at 80 to 90 millions. Two generations of workers have been trained since wood began to give place to iron, and sail to steam. Unrivalled experience has been acquired. We have become the shipbuilders and shipowners *par excellence* of the world. This is a proud position, which cannot be maintained without continued attention to all that makes for improvement and economy.

Foreign shipbuilders have carefully studied our methods, and in some respects may have improved upon them. It behoves us to take careful note of what is being done elsewhere, and to be ready to learn from all capable teachers. Although circumstances have changed in many respects, and in some to our disadvantage, the most confirmed pessimists have hardly dared to include our shipping interests in the lists where foreign competition has become serious or threatens soon to be so. Other nations are naturally making, and will continue to make, vigorous efforts to develop both shipbuilding and shipowning. Some of them have great natural resources in the materials for ship-construction. Judged by the favourite but often misleading method of percentages, the growth of foreign shipbuilding in Germany and the United States is rapid. Looked at in a broad common-sense way, our lead is commanding, and so far practically unchallenged. It should be maintained, if proper steps be taken to maintain it, and if both employers and workers unite in the endeavour. As our present supremacy is largely due to the development of our iron and steel industry, as well as to the great extension of mechanical labour-saving appliances in the construction and working of ships, so must the metallurgist and the mechanical engineer continue to lend their valuable aid to the shipbuilder. We should never forget the fact that in the later days of wood shipbuilding the United States—being rich in timber while we had to import largely, and having also designers who showed remarkable boldness and skill—made a bold bid for equality. In 1815 the United States possessed about half the tonnage of the United Kingdom. In 1861 they possessed nearly 5,500,000 tons of shipping, while the United Kingdom owned about 5,900,000 tons. With the change to iron,

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and probably to some extent as a consequence of the Civil War, the competition died away. Now the United Kingdom owns over 12½ millions of tons, as against about 2½ millions of tons owned by the United States. Signs are not wanting however that our transatlantic cousins are not content with this relative standing; and we may anticipate a renewal of the old competition, which is another reason for taking heed to our methods and machinery and for neglecting no source of economy in either building or working ships.

On this occasion I do not purpose dwelling upon the remarkable improvements made in the steam-generating and propelling apparatus of modern steamships. Time is not available, nor is it desirable to make the attempt. The history of the wonderful advances made in marine engineering has been ably summarised in our Proceedings by Sir Frederick Bramwell, Mr. Francis C. Marshall, and the late Mr. Alfred Blechynden. Another chapter in this history is now nearly due, and I trust will be contributed before long by some equally competent writer. Nor can we leave unnoticed the valuable Reports on Marine-Engine Trials by our Research Committee, so ably presided over by Dr. Kennedy. It may be doubted whether any of the lines of Research promoted by the Institution has been productive of greater practical results, or more suggestive of possible improvement. While I am compelled to pass by without further notice this important section of the work of the mechanical engineer, it is only right to say that the change from sail to steam, even for the longest voyages, with all its contingent advantages, could never have been made but for the inventive genius which has economised the coal-consumption, increased the power developed from a given weight of machinery, and accelerated as well as made more regular transit across the sea.

Even with this omission, there remains a most extensive field to survey, when dealing with the influence of mechanical engineering on shipbuilding. It will be convenient to range my remarks under the two great divisions of the *Shipyard* and the *Ship*.

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Mechanical Engineering in the Shipyard.

So long as wood was the principal material employed in shipbuilding, manual power reigned supreme in the largest and best equipped shipyards, including the Royal Dockyards. Machinery was used little, if at all, in the operations of shaping, fixing, combining, and fastening the various parts of ships' structures. Remarkable results were achieved under these conditions. The towering three-deckers, now serving as hulks at our great naval ports, are monuments of the constructive skill of the shipwright, based on the experience of centuries, with wood as his material and only simple hand-tools. If I may refer to my own recollections when as a lad I entered Devonport Dockyard forty years ago, it may serve to illustrate the changes that have occurred since that date in shipyard equipment. A Royal Dockyard then had its steam factory and machine shops for the repair of engines and boilers; its millwrights' shop for dealing with ship-fittings; its steam saw-mills for converting timber; its roperies with suitable machines; and special departments for block-making or other manufactures. A few steam-hammers were to be seen in the forges. Steam cranes and capstans were installed around the basins, and steam pumps were used for the docks. But, for shipbuilding proper, manual labour held its own. Individual pieces of the structure were shaped by hand, and lifted by hand-power winches, as their size and weight were not considerable. Attempts were made from time to time to introduce new machines and to diminish hand-labour. Few of these succeeded. Even in the joiners' shops wood-working machines were then but little used. One incident dwells in my memory. An experimental machine was erected for cutting out the frame timbers or "ribs" from the logs. It was ingeniously contrived to cut curved and bevelled timbers for large warships, and to relieve the sawyers from the heaviest work. After an extended trial however, in competition with the hand-sawyers, it was agreed that they could beat the machine, and its use was discontinued.

The contrast between these conditions and those now to be seen in a modern shipyard is extreme. Machinery and labour-saving

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appliances abound, and are essential to rapid and economical working. With ships of increased dimensions, scantlings have become heavier, the sizes and weights of plates and bars have increased, special arrangements have had to be made for transporting and handling materials, and the power of all classes of machinery has had to be increased proportionately. In a well-equipped yard the most careful consideration is given to every step necessary in dealing with materials from their delivery up to the time when they find their places in the structures of ships. The stacks of plates and bars are so situated that the materials can be readily lifted from the trucks on arrival, or out of the depot when required for use. Travelling cranes or gantries command the whole depot. Bogies, in many cases running on light railways, convey the materials to the machine shops, furnaces, or bending slabs, where they are shaped and prepared for erection, being afterwards similarly transported to the building slips. A large number of cranes are used for handling the materials with a minimum of labour while at the machines. At the building slips also mechanical lifting appliances are freely used. Hitherto manual power has been chiefly employed in fixing and riveting together the several parts of the structure. Serious attempts are now being made to extend the use of machinery even to these portions of the work. Some of the leading firms have erected at their building slips large travelling cranes or gantries capable of moving along the length of the slips, as well as commanding the whole breadth. These locomotive lifting appliances can be used for both erecting and putting into position parts of the structure, as well as for carrying portable machine-tools. Messrs. Harland and Wolff made use of a very large installation of this kind in building the "Oceanic." Hydraulic power was chiefly employed by them, and powerful machine-riveters were used extensively, the plating being of unusual thickness. Messrs. Swan and Hunter of Wallsend, near Newcastle-on-Tyne, have adopted another plan. Shipbuilding sheds of special design have been built over the slips. These sheds give shelter to the workmen in bad weather, and facilitate many of the operations of erecting and fastening parts of the structures. They also carry a very complete arrangement of overhead electric

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cranes, which travel the whole length of the slips. These cranes lift and put in place frames, beams, and plates, as well as carry certain machine-tools. At the Newport News shipyard in the United States electrical appliances have been adopted for work of a similar nature. In all these cases it is understood that the large initial outlay has been justified by experience, especially in building heavy ships. This is readily realised when it is remembered that from 7,000 to 10,000 tons of material have to be built into the largest ships of the present day, and traversed over lengths of 500 to 700 feet, as well as lifted to great heights in many cases.

Some firms are content with simpler arrangements, such as derricks with mechanical power for lifting. No doubt such devices are of real service, and they permit of easier readjustment under the varying conditions of shipyard work. Ships have grown rapidly in size, and will probably continue to do so. With more elaborate and permanent appliances there is a difficulty in foreseeing what margin should be provided, beyond the maximum requirements of the period when the appliances are designed. In the Royal dockyards, for example, and in some private yards, where sheds existed over building berths, they have had to be removed in order to provide for ships of unprecedented dimensions. I have seen cases where ordinary sheer-legs, with mechanical power for hoisting, have been found more useful for fitting armour-plates on the sides of a battle-ship than travelling steam-cranes. Facts of this nature however in no way contradict the general principle that well-considered lifting appliances are of great utility in building ships.

In the early days of iron shipbuilding the machine-tools of shipyards were comparatively few and simple, mostly borrowed from boiler-shop practice. Since then shipyard machinery has been greatly specialised, and reconstruction of plant has become necessary from time to time, in order to meet changed conditions. At first steam power alone was used. Now hydraulic, electrical, and pneumatic power are used as allies of steam power or substitutes for it.

One of the most notable hydraulic installations was described by M. Berrier-Fontaine in a valuable paper contributed to our Proceedings (1878, page 346). It was designed by one of our members,

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Mr. Ralph H. Tweddell, and was set up at Toulon in the French government dockyard. Hydraulic power as a rule finds its most general use in cranes and other lifting appliances, as well as in powerful presses used for flanging, "joggling," punching out lightening holes, and other heavy work. It is also used for riveting work that can be brought to the machines, and to a limited extent for portable riveters.

Electrical power is being extensively used in some of the best equipped shipyards, apparently with satisfactory results. It is probable that it will be much more extensively employed before long. For large machines with separate motors, and for groups of smaller machines, electric driving has much to recommend it. For operations that have to be performed *in sitú*, portable electrical machines are found most useful. As examples reference may be made to electric drills, planers for wood decks, cutters for large holes in plating on sides or decks, caulkers, and riveters. In some cases, especially in elaborately fitted warships, it is found advantageous to establish on board temporary machine-shops, which can be most conveniently driven by electric power. Many operations are thus rapidly and economically performed, which would otherwise necessitate the transport of fittings to and from shops in the yards. Portable electric-light apparatus for use on board ships while building is now generally recognised to be advantageous and economical. The arrangements made for lighting are readily extended to include driving the machines above mentioned.

Pneumatic power has not been much used in shipbuilding. It has found employment however for such operations as caulking and riveting. Mr. Babcock of Chicago has recently published the results of his experience with pneumatic riveters, and he is strongly of opinion that they can be advantageously adopted for work at the ships. As a rule nearly all such work is done by hand, although machine-riveting is largely used for work that can be taken to machines. Every shipbuilder would be glad to have a light and satisfactory portable riveting machine, which could be used in all the varying positions and conditions occurring in shipwork. Many attempts have been made to find a mechanical substitute for the heavy manual labour involved in satisfactorily "closing" and riveting shell

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and deck plating. If this can be done, there should be a considerable economy in cost, and many disputes with workmen would be avoided. As yet success has not been attained, except with special appliances: such as have been described as erected by Messrs. Harland and Wolff for carrying hydraulic riveters, or others used for riveting garboard strakes and keels. I have seen steam riveters and electric riveters under trial, and now good things are said of pneumatic riveters. Here is an opening for the mechanical engineer, who should master the essential conditions by careful observation of shipbuilding practice, as a preliminary to his design of a suitable riveter.

In all branches of engineering it is essential to economy of production that the manufacturer should furnish materials of the dimensions and forms best adapted to combination in the structures to be produced. In floating structures such as ships, economy in weight, with adequate provision of strength, is of the highest importance, resulting in corresponding addition to carrying power and earnings. Even if economy of weight has to be obtained by increased first cost of materials, it is, as a rule, well worth having; and in many instances carries with it savings in the cost of construction. The principle is sound enough, and has long been recognised, especially in warship-building. With iron as the material, it had not nearly the same range of application as is now possible with steel. Special sections of bars and beams are readily produced in steel, which were hardly obtainable in iron. Z bars, H bars, channel bars, T bulbs, angle bulbs, and other sections, have come into general use, taking the place of built-up combinations of plates and angles with rivet connections. Economy in weight and labour is thus obtained; but special appliances are needed for working some of these special sections. With steel much larger plates are produced, and riveting is lessened. In the "Oceanic" the majority of the plates in the central portion of the vessel are said to be each over 28 feet long, about 4½ feet wide, and from 2 to 3 tons in weight. Iron plates of 12 to 14 feet in length and 3 to 4 feet in width would have been considered of large dimensions, and the riveting work in butts and edges would have been proportionately greater than with the larger steel plates.

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The shipbuilder is under great obligations to the steelmaker for this progress in manufacture; but the mechanical engineer has had a hand in its achievement, by designing and making the machinery and plant used in the steel-works. In the device of new and more powerful machines for the shipyard his work has been more obvious. Without such machines the superior working qualities of steel could not have been utilized as is now done. Operations are now commonly performed on steel plates in a cold state that were not possible with the best qualities of iron. Flanging is extensively practised, to form stiffeners or to make connections such as were usually formed in iron ships by riveting angles on plates. The edges of skin-plating and deck-plating are "joggled," and the use of "liners" or "packing pieces" is avoided. Steel plates are bent and worked to difficult forms necessary in certain parts of ships, where castings were formerly used. Lightening holes are punched out of comparatively thick plates, and in many other ways weight and cost are reduced by the use of special machines. Many of these are worked by hydraulic power, and it is difficult to imagine a better application of that power than is seen in modern flanging and punching machines.

In concluding these remarks on shipyard machinery it may be of interest to enumerate briefly some of the principal machines now in use.

Flanging Machines.—Capable of flanging cold at one stroke plates up to 33 feet in length and $1\frac{1}{4}$ inch in thickness. Less powerful machines are used for thinner plates up to $\frac{3}{4}$ inch. Most of these machines are hydraulic.

Joggling Machines.—Capable of dealing with plates up to 1 inch in thickness; also with angle bars. Most of these machines are hydraulic.

Shearing Machines.—Capable of shearing plates up to 2 inches in thickness; and of dealing with Z bars and angle bars. These very thick plates occur in the protective decks of warships.

Punching and Lightening Machines.—Capable of punching at one stroke large lightening holes out of plates 1 inch thick. Also of punching rivet-holes in plates up to $1\frac{1}{2}$ inch thickness. A few can punch up to 2 inches thickness.

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Bending Rolls.—Capable of bending plates 30 to 35 feet long and 1½ inch thick.

Straightening Rolls.—Capable of dealing with plates 7 feet wide and 1½ inch thick.

Planing Machines.—Capable of dealing with plates up to 35 feet long, or batches of plates. Some of these machines plane edge and butt simultaneously.

Bevelling Machines.—Capable of dealing with angle-bars and Z bars while hot.

Radial Drills and Countersinking Machines.—Fitted with revolving arms 8 feet long, traversing through 180 degrees: capable of drilling holes up to 3 inches in diameter, or much larger holes with special cutters. Countersinking machines can deal with 700 to 1,200 holes per hour, according to thickness of plates.

Most of the larger shipyard machines are now fitted with hydraulic lifts and cranes for dealing with the plates &c. while they are at the machine, and lifting them on and off the bogies or trucks on which they are transported through the yard.

Mechanical Engineering on board Ship.

The development of mechanical appliances for the equipment and working of ships during the last forty years is no less remarkable than that which has been briefly sketched in connection with shipbuilding. At the earlier date, apart from the propelling machinery, manual power only was employed in the largest and best found ships. Work on masts and sails, steering, loading and unloading cargo, lifting and lowering boats was all done by hand-power, aided by simple mechanical appliances. In warships the armaments were hand-worked; gun-carriages, training gear and ammunition-supply were all of the simplest character, and practically unchanged in principle as compared with those which had been used for centuries. Our first sea-going ironclad, the "Warrior," laid down in 1859, may be taken as an example of the best practice at that time. In the original design steam-power was applied, apart from propulsion, only to pumping and ash-hoisting. The pumping was

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done partly off the main engines, and partly by an auxiliary engine added during the building, which also worked the ash-hoisting gear by means of chain and spur gearing. A full equipment for sailing was provided; all the work in this department was done by hand. When the vessel sailed, the screw propeller was raised out of water in its banjo frame. A weight of 32 tons had to be lifted, and this was done by means of special purchases. In working spars and boats the heaviest weights dealt with were from 5 to 6 tons. Steering was a formidable operation. Between the steering wheels and the tillers there was a multiplication of tackles to gain power, and at full speed forty or fifty men worked at the wheels and relieving tackles, even then moving the rudder very slowly, and to moderate angles. Heaving in anchors and cables was a slow and laborious operation, accomplished by fitting capstans on two decks and crowding men on the bars.

In the mercantile marine the conditions were very similar. Cargo steamers were equipped with hand-worked appliances for loading and unloading. The winches were similar in character to those used from early times in sailing ships, the lifting power being moderate, and working slowly except with light loads. Hand-power was used for cable work, steering, and working spars and sails.

Now the conditions of working are entirely changed. Mechanical power is extensively employed, manual power is minimised, comfort and habitability are enormously increased, steering is made easy in the largest and swiftest vessels, loading and unloading of cargoes are accelerated, anchors and cables are worked safely and rapidly by a few men. Without entering into details it may be interesting to glance at a few of the principal applications of mechanical power, and their influence on the working of ships.

Steering.

Steering naturally takes the first place. In the introduction of efficient steam-steering appliances, one of our Members, Mr. Macfarlane Gray, has played a distinguished part (Proceedings 1867, page 267). From him I learn that the first steps were in 1866, as the result of

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difficulties that had occurred in steering the "Great Eastern," and on the suggestion of the late Sir James Anderson, who was the commander of that ship. Mr. Gray's invention of the differential gear enabled the steering engine, when placed at a distance from the navigating station, to be controlled by the movement of the steering wheel: so that the helm could be made to follow, and assume any desired position. The first trial on the "Great Eastern" was made in March 1867, and proved successful. It led eventually to the general adoption of steam-steering gear, although some time elapsed before the full advantages were realised. The Admiralty took the system up on the recommendation of Sir Nathaniel Barnaby, and applied it to the "Minotaur" class—the longest warships then afloat—where difficulties in steering by hand had occurred. No better illustration could be given of the advantages of steam-steering than are afforded by the trials of the "Minotaur." With manual power eighteen men were employed at the wheels and sixty at the relieving tackles. They took $1\frac{1}{2}$ minute to put the helm over to 25 degrees, and $7\frac{2}{3}$ minutes were occupied by the ship in turning through 360 degrees. After steam-steering was adopted, two men at the wheel put the helm over 35 degrees in 16 seconds, and the ship turned in $5\frac{1}{2}$ minutes and in two-thirds the space. For all ships such a gain in manœuvring power is of immense value; for warships the utmost handiness is essential, and their rudders are proportionately much larger and more difficult to work. No wonder therefore that nearly all steamships are now fitted with mechanical steering gear: mostly steam, in some instances hydraulic, and in a few recent ships electrical. Many arrangements have been devised subsequently for effecting the same object as was attained by Mr. Gray. Some of these are remarkably ingenious. It is but right however that he should have the credit of being the pioneer in this important change.

As an example of the latest practice in the Royal Navy, it may be stated that in a first-class battleship or cruiser there are two independent steering engines, each of which can move the rudder through 70 degrees in 30 seconds when steaming at 18 to 23 knots. The maximum turning moment on the rudder head, in the case of a battleship steaming at 18 knots, is estimated at 450 foot-tons.

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Proposals have been made, and some of them have been worked out in detail, for automatically steering ships on a given course. While this is a mechanical possibility, the plan has not found favour in practice, nor is likely to do so. Under the actual conditions of navigation there is obviously a constant need for human watchfulness and control; while the maximum economy obtainable by the use of such automatic steering gear is comparatively unimportant.

Capstans, Windlasses, and Cable Gear.

Manual power has practically ceased to be used for working anchors and cables in steamships. Steam power is generally employed, hydraulic power has been used in some cases, electrical power is coming into use. Anchors and cables in the largest ships are too heavy to be satisfactorily dealt with apart from mechanical appliances, and in smaller vessels similar appliances economise labour. These appliances have to be devised in such a manner as will fit them to withstand sudden and severe shocks and stresses inevitably occurring in service; while they must be capable of controlling the cables when at anchor, or when mooring or unmooring. The details of the mechanism in modern capstans and windlasses show great ingenuity, as well as capacity for standing rough usage. The engineering firms who make a speciality of the design and manufacture of these appliances deserve great credit for what they have accomplished.

In the Royal Navy it is the practice to fit capstans so that they can be worked either by hand or by power. Taking a large battleship of 15,000 tons, the forward capstans have to deal with $2\frac{9}{16}$-inch cables, weighing 16 tons for each 100 fathoms, and with anchors each weighing 6 tons. It is required that these capstans shall be capable of lifting 35 tons at a speed of 25 feet per minute; and this is practically tested in each ship.

In the largest classes of merchant steamers, cables up to $3\frac{1}{4}$ inches are now used; whereas thirty years ago there were few vessels with more than $1\frac{3}{4}$-inch cables. The speed of lifting the anchors does not usually average more than 40 feet per minute.

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Ventilation.

Artificial ventilation, chiefly by means of fans, is now largely employed in many classes of ships, and especially in warships. The arrangements include both supply of air to the stokeholds and furnaces, and supply to the living spaces. In some instances the living spaces are dealt with by exhaust fans, a natural supply of fresh air being depended upon. Perhaps the greatest demands arise in connection with the general adoption of systems of mechanical draught to stokeholds and furnaces, supplementing the funnel draught. All these requirements affect the work of the mechanical engineer, leading to the construction of new types of fans and fan-engines.

Electrically driven fans are now coming into extensive use on shipboard, and are an excellent application of that form of power. Cases have often occurred in warships where the introduction of a steam-driven fan for the purpose of ventilating a compartment situated low down in the hold and containing machinery has been of doubtful benefit. The effect of a better air-supply has been almost neutralised by the additional heat caused by the fan-engine and its steam connections. With electricity, difficulties of this kind can be avoided and other simplifications made, including smaller air-shafts, better maintenance of watertight subdivision, and less waste of power.

Warships, with their complicated subdivision, armament, and protection, present the most difficult problems. In them it is necessary to provide for ordinary conditions of navigation or service in very varying climates, as well as for the special condition where they are in fighting trim, with all the hold spaces below the protective deck closed down, and most of the doors in watertight bulkheads also closed. As an example of recent practice, not the latest, it may be stated that in a first-class battleship, outside the machinery and boiler spaces, there are fifteen 24-inch fans driven by electric motors, each fan being capable of delivering 1,500 cubic feet of air per minute at the end of its air-trunk. In the boiler rooms there are ten fans 6½ feet in diameter, driven by open double-acting steam engines; and in the engine rooms two similar fans.

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Passenger steamers of high speed are commonly fitted with powerful ventilating appliances both for living spaces and for machinery and boiler spaces. In these vessels the conditions are simpler than in warships. Cargo steamers also require careful treatment as regards ventilation, especially with certain kinds of cargo, such as coals and oil.

Internal Lighting.

In all classes of steamships electric lighting is becoming the rule, and no better evidence of its advantages need be required. While it is most desirable in living spaces, it is practically essential to good working and efficient maintenance of machinery. For ship purposes, special water-tight fittings are desirable. In other respects the installations present no special features requiring mention. In warships the "search-light" fittings are of a powerful character. In merchant ships less powerful lights suffice.

It is probable that the general adoption of internal electric lighting will tend to a wider use of electrical power for many auxiliary purposes. A notable effect on the working of all classes of ships has been produced by the introduction of electric lights. The passage of the Suez Canal is now made by night as well as by day: ports are entered and left at night with safety: and coaling, loading or unloading, &c., proceed unchecked. In many other ways economy and speed of working are promoted.

Pumping.

Mechanical power is now universally employed for pumping purposes in steamships. A few hand-pumps may be fitted, but they are used only in exceptional circumstances or for special work. Steam-driven pumps are generally preferred. Pumps driven by electro-motors are now coming into use. For the ordinary service of ships ample pumping power is provided. In merchant ships, where water-ballast is commonly used with economical results, the pumping arrangements are specially arranged for rapidly clearing the ballast-tanks. Oil-carrying steamers have powerful pumps for dealing with their liquid cargoes.

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While ample pumping power is desirable and of service in many circumstances, it is now generally agreed that the best protection against foundering is good watertight subdivision of the hold-space. The undue development of pumping power with a view to dealing with serious injuries from grounding or collision is admitted to be undesirable, since it is hopeless to attempt to meet a serious leak by pumping when there is free communication with the sea.

Lifting Appliances.

In no department has the equipment of modern ships received greater development than in lifting appliances. One of the most marked tendencies in recent construction has been increase in the size and carrying power of ships. Unless there had been a corresponding development in the means of dealing with cargo, this increase of size could hardly have occurred, and the advantages resulting therefrom would not have been realised. It is a principle in ship-designing that, as ships increase in size, the expenditure of power and fuel for a given speed becomes relatively less, and the "useful displacement" or "carrying power" becomes relatively greater. In other words, as far as sea transit is concerned, the ratio of earnings to expenses in the larger ship should be greater than the corresponding ratio in the smaller. On the other hand, it is well recognised that, unless there is quick despatch in loading and unloading cargoes, serious diminutions of earnings must result from the longer detention in port. Hence it follows that, for the complete commercial success of the larger classes of cargo carriers, lifting appliances of the most efficient character and of ample capacity are of the greatest importance. The prevision of the shipowner, in collecting the cargo and having it ready to load, would be ineffective unless the mechanical appliances were adequate.

Remarkable progress has been made by mechanical engineers in meeting these demands. Certain firms have made a special study of lifting appliances on board ship; and I owe the following summary of progress to my friend Captain Chapman, the head of one of these firms. Thirty years ago most cargo steamers were fitted with hand-power

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crabs or winches, similar to those long used in sailing ships. Then came the fitting of engines to winches of the old pattern, the engines being placed diagonally. To reduce the strains on decks, and facilitate working and repairs, horizontal steam-winches were introduced. For many years these winches had cylinders not exceeding 5 or 6 inches in diameter with 10 inches stroke. The lifting barrel was about 10 inches in diameter, and took the cargo chain-runner. Two warping drums were fitted on the slow-speed shaft, while the quick-speed shaft carried "whipping" drums. Until twelve years ago four or five such winches formed the lifting equipment of a cargo steamer. Now in the largest steamers from twelve to twenty winches are fitted, besides cranes. Winches have cylinders from 7 to 10 inches diameter. They are fitted with large barrels and outer drums on the slow-speed shafts, as well as smaller drums on the quick-speed shafts. By this means five drums are made available on each winch, and by suitable arrangements of "spans" from mast to mast with falls attached, forty to fifty whips for lifting light loads may be kept going simultaneously by eight or nine winches. Steam is turned on to the winches, and they run all day except at meal times. As a rule light loads, say from 2 to 3 cwts., are thus dealt with. Heavier loads can of course be dealt with by different arrangements, say up to 6 or 7 tons.

Besides the winches, derricks are extensively used for lifting, being carried by the masts or by derrick posts. Cranes, standing upon the decks, are also largely used.

Great care is bestowed upon the details of all these appliances, in order to economise power and increase rapidity of working. With higher steam-pressures this is a most important matter, and considerable variations of pressure have to be provided for.

Cargoes of a special character—such as coal, ore, grain, and oil—require to have special arrangements made for both loading and discharge. Bulky materials, such as cotton, require to be compressed into the narrowest possible limits for storage in the holds of ships. Here again the mechanical engineer has played an important part. It is not possible nor desirable for me to dwell upon the details of coal shipping, grain elevators, ore piers and shoots, oil pumps and

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storage, important as these are to the successful working of many classes of ships. American engineers have undoubtedly shown the way in many directions, quickened no doubt by the high price of labour in the United States. British engineers have done great things also, and must not always expect to be leaders in improvement, nor should they be adverse to benefiting by the work of others. In fact they must take care that British shipowners continue to have at their command the most perfect appliances for loading and unloading cargoes.

As an example of present conditions I may present the following facts, which I owe to the kindness of my friend Mr. Thomas Ismay of the White Star Line. The "Cymric" is an excellent example of a modern cargo-steamer. Her measurement capacity is about 19,400 tons, her dead-weight capacity about 12,000 tons, excluding coal. Her cargo space is divided into seven holds, each of which is subdivided into three compartments, namely 'tween decks, orlops, and lower hold. Five of these compartments are fitted as refrigerators, with a total capacity of about 2,200 tons. There are 9 hatchways, 15 derricks, 17 steam winches for cargo purposes, and mast-head "spans." The capability of these appliances is illustrated by the fact that she has commenced discharging a full cargo at 7 a.m. on Monday, completed her loading of cargo and taken on board 1,600 tons of coal, and undocked at noon on the following Friday. Loading and unloading were carried on to a great extent concurrently, about 400 to 450 men were employed, and the average rate of discharge was not less than 300 tons (weight) per hour, the corresponding rate of loading being about 250 tons. All the general cargo, apart from bulk-grain &c., was weighed at landing. When it is remembered that in such a general cargo there may be 30,000 to 40,000 packages to be dealt with, these results are evidence of both excellent mechanical arrangements and perfect organization.

The Hamburg American S.S. "Pretoria" has 14 powerful steam winches, 8 steam cranes capable of lifting 3 tons each, and is so fitted that about 40 lifts can be undertaken simultaneously.

Steam power has been principally employed hitherto for these lifting appliances. Hydraulic power has been used to a limited extent, but with complete success. Electrical power is now applied in some cases, and will probably be more extensively used in future.

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Refrigeration.

This is one of the most recent, and at the same time one of the most important applications of mechanical engineering on board ship. It is not yet twenty years since the frozen-meat trade was begun between Australia and England. At the outset comparatively small cargoes were carried; but as machines were improved and experience was enlarged, so larger cargoes were carried, and a new branch of the shipping industry was created. Sir Alfred Haslam, who has done so much to develop this branch of mechanical engineering, has at my request given me some interesting facts. The first refrigerators were designed to deal with 150 tons of meat. Now machines are constructed capable of dealing with 3,000 tons, while they occupy only 2½ times the space and consume about three times the coal required for the first machines. In 1881 about 14,000 carcasses were brought to this country from the Colonies; in 1899 it is anticipated that from 8 to 9 millions will be delivered from the Colonies and various parts of the world. In addition to dead meat, large quantities of butter, fruit, and other perishable cargoes, are now carried from the far ends of the earth, and delivered in good condition. Thanks to the enterprise of the shipowner and the ingenuity of the mechanical engineer, the British Empire is becoming self-contained and self-supporting, since the natural products of all parts of the Empire suffice to meet all needs, and the cost of conveyance across the sea is minimised by the skill of the shipbuilder and the marine engineer.

Time does not permit me even to touch upon the relative merits of various types of refrigerating machines. Cold-air machines were first used, and still find favour for use on board ship. Ammonia compression machines and other chemical machines are also used.

Nor can I do more than allude to the enormous scale to which cold storage on shore has grown. The first stores at the London Docks held about 400 tons of meat, or 16,000 carcasses. Stores now being completed at the Victoria Docks will hold about a million carcasses. The first refrigerating machine used in connection with these stores in 1880 was equivalent to the melting of 21 tons of ice

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in twenty-four hours. A machine is now in construction which has about tenfold as great power.

All who travel by sea know how much health and comfort are promoted by the change in dietary made possible by refrigeration. In recent years refrigerating chambers have become a part of the equipment of the larger classes of ships in the Royal Navy. Two machines are usually fitted, each of which has to be capable of reducing the temperature of a chamber of 1,800 cubic feet capacity to 15° Fahr., and of easily maintaining this temperature when the atmosphere and sea-water are at 100° and 85° Fahr. respectively. The atmosphere in the chamber must also be kept perfectly dry.

Mechanical Engineering in Warships.

The auxiliary machinery of warships necessarily has much in common with the corresponding machinery in merchant ships. There are however many special requirements arising from their armament and equipment as fighting machines; and hence it happens that in warships the applications of mechanical power reach their fullest development. Modern warships are sometimes styled "boxes of machinery," and the description is not inapt. The tendency is, in fact, to multiply machines and to minimise manual labour, to an extent which is not universally approved. On the other hand, with modern armaments and equipment, an extensive use of mechanical power is inevitable, and the expenditure of fuel on auxiliary services grows greater in proportion to that devoted to propulsion.

Ten years ago, in a first-class battleship of 12,000 H.P. (maximum) for the propelling machinery, there were fifty auxiliary engines capable of indicating in the aggregate about 5,000 H.P. if they all worked simultaneously, which of course they did not. Today a similar statement would show a growth in the auxiliary power as compared with the propelling.

The multiplication of auxiliary services makes serious demands upon the coal supply of warships. Even in harbour the expenditure of coal is large on lighting, distilling, ventilation, air-compression, drilling with the heavy guns, and other services. From 10 to 25 tons a day may thus be expended in a large battleship or

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cruiser of high speed. As warships cruise at low speeds and spend much time in harbour, it results that, taking the year through, fully as much coal is burnt for auxiliary services as for propulsion. Coal endurance being one of the most important factors in warship efficiency, facts such as these have tended to cause a doubt as to the wisdom of more widely extending mechanical appliances. It is pointed out that manual power with simple fittings, such as can be readily replaced if damaged in action, can compete with mechanical appliances in many directions; and that it is better to have larger crews in fighting ships, so as to provide a margin for inevitable casualties, than to use the alternative of labour-saving machines liable to derangement or injury and not easily repaired in action. The practical solution of the problem clearly lies in the due proportion being found between manual and mechanical appliances.

Gun construction in its modern form is largely dependent upon mechanical engineering. Our Past-Presidents, Lord Armstrong and the late Sir Joseph Whitworth, were famous as mechanical engineers before they undertook the design and manufacture of guns. In this Address however, the story of progress from the smooth-bore cast-iron 68-pounder, weighing 95 cwts., to the 110-ton breech-loading rifled gun, firing 1,800-lb. projectiles, can find no place. Nor can more than a brief glance be bestowed upon the interesting work done by the mechanical engineer in regard to appliances for mounting, working, and loading modern guns, supplying the ammunition, and securing rapidity and accuracy of fire with a minimum of labour.

Anyone who will study the breech mechanism and mounting of a hand-worked quick-firing gun will discover a triumph of mechanical engineering over a special and difficult problem. Take for example a 6-inch quick-firing gun of the latest naval pattern. The gun weighs about 7 tons, fires 100-lb. projectiles with a muzzle velocity of nearly 2,800 feet per second, and with an energy of 5,370 foot-tons, corresponding with a penetration of 22 inches of wrought-iron. Its breech mechanism is so devised that four or five aimed shots can be fired per minute. Its mounting is so arranged that the gun can be easily trained, elevated, or depressed by one man. The great energy of recoil is perfectly controlled, and the crew numbers

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only four or five men. If such a gun is compared with the 68-pounder smooth-bore muzzle-loader, which I well remember, mounted on a wood truck carriage, with rude arrangements for elevating, and still ruder for training and controlling recoil, a striking illustration is obtained of the progress made in forty years with hand-worked guns.

When we pass to heavier guns worked by mechanical power, a still greater contrast appears. The 110-ton gun of 16¼ inches calibre has charges of 960 lbs. of powder and 1,800-lb. projectiles. Fired with a velocity of 2,100 feet per second, these projectiles have an energy of 54,000 foot-tons, with an estimated penetration of 37 inches of wrought-iron. Obviously manual power alone would be unequal to working such guns. The mechanical engineer has devised suitable machinery which enables pairs of guns, mounted in a thickly armoured turret, to be loaded, trained, elevated, and depressed with ease and comparative rapidity under the guidance of a few men. Mr. George Rendel was probably the first, as well as one of the most successful, designers of mechanical appliances for working heavy guns by hydraulic power. Messrs. Armstrong have from the first taken a leading position in this class of work. Messrs. Whitworth, and in more recent times Messrs. Vickers, have also undertaken it on a large scale. Hydraulic power finds most favour in the Royal Navy. Abroad electrical power is now extensively used. Pneumatic power has been employed in a few cases.

Improvements in gun-design and in explosives have resulted in an increased ratio of power to weight in the latest types of guns. As a result in the latest completed battleships, guns of 12-inch calibre, weighing 46 tons, firing 850-lb. projectiles, with muzzle velocities of about 2,400 feet per second, and energies of 33,000 foot-tons have been used, instead of the 67-ton and 110-ton guns of earlier date. These reduced weights of charges and projectiles are more easily handled; and this fact, together with certain changes in the system of mounting, have enabled many of the operations of loading and working the guns to be performed by manual power as well as by hydraulic power. This duplication is obviously advantageous, and reduces greatly the risk of heavy guns being put out of action. There was a time when a return to guns of still smaller dimensions,

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capable of being worked exclusively by hand-power, was strongly advocated. It was urged that it was unwise to depend at all on mechanical power, because it might fail at a critical moment. Such arguments are now but little heard. Experience does not demonstrate that any serious risk of breakdown need be feared in mechanical appliances. Moreover the advocates of manual power overlooked the fact that, supposing their system had been adopted, there must still have remained in all modern mountings and breech mechanisms many comparatively delicate parts, perhaps more liable to injury or derangement than the appliances which were objected to.

Steady improvement has been made in heavy gun mountings and in rapidity of fire. For example, with 12-inch guns from 2½ to 3 minutes were formerly considered to be a reasonable interval between successive rounds, and in foreign navies twice that time was not thought too much; now the interval has been brought below 1 minute, when pairs of guns are loaded and fired. Loading has also been made possible with the guns in any position; whereas formerly the guns were brought to fixed hoists, and to a definite angle of elevation for loading. It is most interesting to watch the working of these heavy guns, by means of mechanisms controlled by a few men. All the operations are performed with rapidity and precision, from the moment when projectiles and charges are moved from their stowing positions in shell rooms and magazines situated deep down in the holds, up to the time when they are rammed home in the gun, the breech closed, and the gun made ready for firing. Then the captain of the barbette or turret is seen training or changing the elevation of the gun up to the instant when he fires by electricity, and the huge projectile is discharged.

Passing from guns to torpedoes, we find a fresh example of the important work done by mechanical engineers. The inventor of the automobile torpedo, Mr. Whitehead, is an eminent member of the profession. The torpedo itself is a beautiful example of mechanical engineering. All the machinery connected with air compression and storage, all the arrangements for ejecting above or below water, involve skilful mechanical design. Nor is this all. From the introduction of the torpedo has sprung the necessity for special

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structural and defensive arrangements in warships; as well as the construction of the swift torpedo flotilla-boats, destroyers, gunboats and depot ships, whose performances are not merely remarkable, but suggestive of possibilities in regard to steam navigation at high speeds.

The smaller classes of boats using the locomotive torpedo have to be carried by warships. They weigh, fully equipped, 18 to 20 tons; or about three times as much as the heaviest load ordinarily dealt with in merchant ships by their own lifting gear. This has involved the design of special lifting appliances for warships. After long experience in the Royal Navy the most suitable arrangement has been found to be a strong steel derrick carried by the mast, with powerful steam or hydraulic hoists working tackles which lift the boats and top the derrick. Winches or capstans are also used in some instances for swinging the derricks. Admiralty specifications require that the lifting gear shall be capable of dealing with a load of about 18 tons lifted by a single wire-rope, as well as with a load of 9 tons raised 30 feet per minute. In one ship, the "Vulcan," built as a torpedo-depot ship and boat-carrier, instead of derricks two powerful hydraulic cranes are fitted (Proceedings 1892, page 247). She carries six steel torpedo-boats 60 feet long and of 16 knots speed, besides sixteen other boats, some of large size. The total weight of these boats is 150 tons, and they are placed 27 feet above water. The two cranes and their gear weigh 140 tons; the tops of the cranes are 55 feet above water. It required careful designing to meet such exceptional conditions satisfactorily, and to produce a stable and seaworthy ship. She has now been many years on service, and has a good reputation.

Besides these special boat-lifting appliances, warships commonly have special coal-hoists, transporters, and other gear for the purpose of accelerating the taking of coal on board. Rapidity in coaling must be of great importance in time of war; and keen competition between ships in the various squadrons as to the rates attained has led to great improvements in details of gear, as well as to remarkably rapid coaling becoming the rule in the Royal Navy. Recently at

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Gibraltar the "Majestic" took on board 1,070 tons of coal in 6 hours and 10 minutes—a very fine performance.

All the larger ships in the Royal Navy have engineers' workshops fitted with a considerable number of machine-tools, which are driven by power, and are of sufficient size to deal with ordinary repairs. The "Vulcan" is a special vessel in this sense also, as she has an exceptionally well-equipped workshop, a small foundry, and a hydraulic press for forgings. For repairs of the boats she carries, or for those of torpedo-boats and destroyers in company, or for certain repairs to ships of the fleet to which she is attached, she has been found most useful. Besides being a floating factory and a boat carrier, she has a large torpedo and mining equipment and an electrical laboratory, and serves as a school of instruction for mining and torpedo work. In addition she is a swift cruiser, with a fair armament and well protected. As an armed ship she represents the fullest application of mechanical appliances afloat. Her construction was commenced in 1887. Other navies have since imitated her.

Another "Vulcan" was fitted up as a floating factory to serve with the American fleet during the recent war. She was originally a merchant steamer, but is said to have proved of great service. Naval opinion seems to favour the use of vessels of this class with fleets. It is held moreover that no modern fleet can be considered to be complete, unless the fighting ships are supplemented by ships specially equipped for distilling and storing fresh water, or carrying coals, ammunition, and reserve stores.

This rapid review of the intimate and extensive connection between mechanical engineering and the building, equipment, and working of ships, has much exceeded the limits I desired to impose, and I fear will have exhausted the patience of my hearers. Even now it is imperfect and incomplete. Enough has been said however to place beyond doubt the correctness of my preliminary statement that the alliance of the shipbuilder and the mechanical engineer has been of immense advantage to our great shipping interests. Since the maintenance of our supremacy on the sea, in both warships and merchant ships, is of vital importance to the Empire, may I not venture in conclusion to assert that the members

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of this Institution, and of the profession it represents, have deserved well of their country by aiding its remarkable maritime developments?

Sir EDWARD H. CARBUTT, Bart., Past-President, said the privilege devolved upon him, as the senior Past-President present this evening, of fulfilling the duty of moving a vote of thanks to Sir William White for the able and instructive address he had delivered. As to a great part of this duty he had been anticipated by the frequent applause which had greeted the President during the course of his address and at its conclusion. At the beginning of the address allusion had been made to Robert Napier, the eminent shipbuilder. Though he had been President of the Institution for three years in succession (1863–4–5), he had once made a remark to the effect that he would rather build a fleet of ships than make a speech. The present distinguished occupant of the presidential chair had shown how ably he could design a fleet of ships; and all who had attended the Institution dinner yesterday evening had heard how good a speech he could make; while the present audience could testify how deserving of the most careful consideration was the address to which they had just listened. Sir William White he believed was rightly looked upon as one of the most remarkable men in England, or in Europe, at the present time. He had designed nearly the whole of the more recent ships in the existing British navy—at any rate, all those which had been built, or were now being built, for the re-construction of the navy; and those ships which had not been designed by him would not be able, he feared, to give so good an account of themselves in any battle in which they might be called upon to engage. Not only had the most powerful warships of modern times and the most powerful cruisers been designed by Sir William, but he had also designed some of the torpedo-boats and torpedo-catchers and ships for carrying coal; and in addition the "Vulcan," which was really a floating engineering factory at sea, and

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moreover carried, besides all her engineering appliances, a large number of boats for the benefit of the fleet. All this work had been done by Sir William White under great pressure. It was not as if unlimited time had been allowed him; but the nation looked to him to design their ships and get them ready in the least possible time. It was indeed remarkable that the most magnificent fleet which any nation in the world possessed—in fact the finest fleet which had ever been seen—had been designed in such a short time, and without a single failure worth mentioning. It was said that every man of energy met with failures; but no one could point to any ship as a failure which had been designed by Sir William White. No doubt complaints were sometimes heard of a piston valve having gone wrong, or a tube in a boiler having leaked; but amid such vast masses of machinery as had to be dealt with in the ships of the navy it could not be expected that everything would go on without an occasional hitch. Although he did not suppose any one objected to fair criticism, for which indeed sensible persons were thankful, yet he thought that many of the questions asked in the House of Commons had often been only carping criticisms, which had done no good. The Admiralty he was happy to believe had come well out of the ordeal; and if any body of men deserved the thanks of their country at this time he considered it was the Admiralty; and if any man connected with the Admiralty deserved the thanks of the nation it was Sir William White, who had done the Institution the honour of becoming their President. He therefore invited the members to join him in according the sincerest thanks, not only of the Institution, but of the whole mechanical world of England and the empire, to the President, Sir William White, for the address he had delivered this evening.

The Right Honourable WILLIAM JAMES PIRRIE, Member of Council, was glad to know that it was one of the privileges of a junior Member of Council to second the vote of thanks. He took this opportunity of assuring the members how highly he appreciated the honour; and he had to thank them for electing him to the Council, as one of the first Irishmen, he believed, who had ever had a seat on

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(The Right Hon. W. J. Pirrie.)

the Council of the Institution of Mechanical Engineers. He also felt much gratified by the kindly reference which in the course of his address the President had made to his own firm in Belfast, in regard to the efforts they had made, not only towards producing the largest ship that had ever been built, but also in adopting some of the many mechanical appliances so rightly mentioned as a necessity for the construction of large ships. The only matter that he thought had possibly not been noticed in the President's hurried visit to the ship-yard in Belfast many years ago was the pneumatic riveting, which had been used there very largely indeed for the last ten or twelve years for the lighter class of work; it was only for larger sizes of plates and rivets that hydraulic riveting was used. What Sir Edward Carbutt had said of the President made him feel relieved to think that he was not a competitor in the designing of the merchant navy. He did not know that he could pay the President a greater compliment than to say that he and others of his profession should dread having Sir William White as a competitor in the designing of merchant vessels. In the merchant service however, no less than in the navy, the designers aimed at continual progress; and no sooner had his firm got a ship just ready for sea, and the trial trip finished, than they told the owners that they saw many mistakes in her, which they could avoid if they were given another opportunity. The navy of the country he was sure, and certainly the mechanical engineers, should feel proud indeed that this Institution had such a President as Sir William White. He seconded the resolution with the greatest pleasure, and was delighted to have the opportunity of doing so. He hoped he should long continue a junior Member of Council, in order to have the pleasure of seconding votes of thanks to the President in the future.

The vote of thanks was carried with applause.

The PRESIDENT believed it was an American ambassador who once, when speaking at the Mansion House, said that the man who made no mistake never made anything. He was not labouring under any illusion that he was himself infallible: for indeed he trusted that as long as he lived and worked he might be

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always his own severest critic. The man who was satisfied with his work, apart from the commercial inducements which might prejudice his judgment in some cases, was to be pitied. He quite agreed with Mr. Pirrie that no one who was worthy of being called an engineer ever finished a piece of work without seeing where he might have done it better. This was particularly true of the address he had just delivered. Having many other matters pressing on his mind, he did not find it quite easy to produce the number of presidential addresses which the present year demanded of him. While he esteemed it a great honour to be asked to occupy the Presidency of this Institution, he could assure the members that he found the office no sinecure. The new year in the new house he hoped might in some respects witness new methods of usefulness; and to these matters the Council were giving their most earnest consideration. They wanted to make the fullest use possible of their increased opportunities for developing the work of the Institution; and signal as it already was, the success of the Institution, if it was to be sustained, must be sustained in a great measure, perhaps in the greatest measure, by the efforts of the members. Scattered about the country, they had an opportunity to increase interest in the Institution; and of course they would themselves reap a share of the benefits thence arising. At any rate he was sure all the members would desire that the Institution should continue to flourish, and they would all be more and more proud of belonging to it. Mr. Pirrie in his concluding words had betrayed his nationality by expressing the hope that he should long remain a junior Member of the Council. For many years it had been his own misfortune to be thought too young for the posts he had occupied; but year by year that argument was ceasing to have much force. He trusted he should live to see Mr. Pirrie high up in the Council of the Institution, and that the time would come when, if he was now the first Irishman to be a Member of the Council, he would also be the first Irishman to be President of the Institution. He thanked the members most heartily for their kind reception of him on all occasions, and for their particularly kind reception of his address.

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(The President.)

There was one announcement which he had not made before, because it did not grow out of the formal business. Since the Institution last met, their friend and Past-President, Mr. Jeremiah Head, had been taken from them: a man who in his time had done a great work for the Institution, and had devoted himself to its interests, and whose death had come all too soon. Having made frequent business visits to America and other countries during his latter years, Mr. Head had never returned without bringing back with him much interesting and practical information, as the result of his own personal observation, which he had most freely communicated to the engineering profession at the meetings of this and other Institutions. In recent years in particular he had drawn attention to the great and rapid adoption in the United States of electric power for the performance of mechanical engineering work, even of the heaviest description. This was one of the salient points to which a portion of the address he had just delivered had been devoted. It was well therefore to bear in mind the memory of their departed friends, and of all they had done for those who were remaining to reap the benefit of their exertions.

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EVAPORATIVE CONDENSERS.

By Mr. HARRY G. V. OLDHAM, of London,
Associate Member.

Advantages of Evaporative Condenser.—The Evaporative Condenser which is now being rapidly developed has forced itself upon the users of large quantities of steam, and of necessity finds a place in the equipment of large generating stations for supplying light and power by electricity. Jet and surface condensers are in many cases prohibited by reason of the large quantities of cooling water consumed, and by the waste of the latter unless some method of cooling it is adopted; this again entails the apportioning of large ground space for the necessary cooling ponds and apparatus. Sometimes large steam engines have thus been compelled to work without a condenser; inability to reduce the back pressure on the piston is then a drawback. When an evaporative condenser is employed, the actual amount of condensing water used may be from 25 to 30 per cent. less than the amount of feed-water used when the engines were non-condensing, and about one-fortieth of the water supply when surface-condensing. Throughout this paper 20 lbs. of steam per hour is taken as the amount required to develop one horse-power.

Principle of Evaporative Condenser.—The general principle of the condenser is simple, and consists in the use of a number of copper, brass, wrought or cast-iron tubes, arranged horizontally or vertically according to the kind of condenser employed. The tubes are connected with chambers at each end; through the inside of the tubes the exhaust steam is passed, and water is allowed to flow over their external surfaces. Part of the water on the external surface is being evaporated, and carries away with it the heat taken from the steam. A more rapid and better result is obtained, if a fan is used to remove the hot damp air.

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It is well known that, at such pressures as have to be dealt with in the condenser, the thermal units in 1 lb. of steam are about 1,000 more than in 1 lb. of water at the same temperature. Before any condensation takes place therefore, it is necessary to withdraw this number of thermal units from the steam. The latter not only heats the circulating water as in a surface condenser, but evaporates a considerable portion of it. Each 1 lb. evaporated from the surface of the tubes takes with it about 1,000 thermal units; and thus for each 1 lb. of steam condensed 1 lb. of cooling water should be the utmost quantity even theoretically required. It has in fact been shown by experiment that only two-thirds of this is practically required, a large amount of heat being dissipated by radiation, conduction, &c.

Distribution of Steam inside Tubes.—The action that takes place inside the tubes is as follows. The exhaust steam which is in contact with the internal surface of the tubes condenses first, causing a momentary vacuum; fresh steam fills its place and is condensed, and so on till the whole is treated. There is a tendency, when the tubes are of a large diameter and the steam passes through without taking a circuitous course, for a central core of steam to pass through without being condensed; it is therefore desirable to stir up the steam, so that the condensation may be more rapid and effective. Internal steam distribution has been provided for by Mr. Row, by whom the indented tube shown in Figs. 7 and 8, Plate 41, is used in exhaust-steam heaters &c. with interesting results. Here the exhaust steam in its passage through the tube impinges against one indented surface and is thrown off against another, being thus split up so as to bring all parts of the steam into contact with the tube. In providing for internal steam distribution, Mr. Wright places a tube of smaller diameter inside the larger upon which the film of water flows. This does not break up the steam, but eliminates the uncondensed core, and utilizes the largest surface of the tube area. Messrs. John Fraser and Son have devised a series of internal spiral distributors, Fig. 15, Plate 42, which are so thin that they do not in any way contract the area through the

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tubes or impede the flow of exhaust steam. The latter on entering the tubes is split into two portions by the spiral partition, which gives the steam a spin as it passes through. The internal distribution in the Ledward tube is shown in Figs. 18 and 19, Plate 42. The exhaust steam follows the transverse corrugations, and is drawn to the surface where they are largest. Though space for a central core exists, it is maintained that the steam is sufficiently disturbed in the tube, from the fact of its having to pass in and out of the corrugations. These act as a trap to any solid matter, and particularly to oil which may be carried over with the exhaust steam.

Distribution of Water over Tubes.—In a great measure the success of an evaporative condenser is due to a proper distribution of the cooling water over the external surface of the tubes. In a vertical-tube condenser the water is delivered into a top receiving tank, through which the tubes pass, the holes in the tank having a larger diameter than the tubes. This leaves an annular space, through which the circulating water flows on its way down each tube into a receiving tank below. In a horizontal-tube condenser the distribution is somewhat different. At the extremities of the rows of tubes and at right angles to them is placed a rectangular tank, into which the circulating water is pumped. Galvanized-iron pipes are led horizontally from the tank, and are carried above each top tube in the condenser. Each pipe is perforated, so as to allow the water to fall over the whole length of each uppermost tube. The water passes round the circumference of the top tube, is collected underneath and distributed over the next below, and so on until it has passed round each tube, and is finally collected in a receiving tank at bottom. The most important methods employed are those of Theisen, Wright, Fraser, and Ledward, Plates 41 and 42.

Theisen uses vertical brass tubes of about 2 inches diameter, shown in Fig. 1, Plate 41. Round each of these is wound in the form of a helix or screw thread a No. 9 gauge (0·150 inch thick) galvanized steel wire, with the view of causing the water to follow this course round and round the tube until it reaches the bottom.

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Wright places round the vertical brass tube brass-plated wire in the form of ordinary galvanized wire-netting, Fig. 2, Plate 41. This appears to give a satisfactory distribution of the water. Later designs have spaces left between the lengths of netting, which allow of the latter being moved up and down for cleaning the tubes and removing scale, as shown in Fig. 2.

In the Fraser vertical condenser perforated conical brass cups are placed round the brass tube, as shown in Figs. 3 and 4, Plate 41, about 12 inches apart, connected by a light rod on each side. It was found by experiment that the rupture of the film of water took place after falling about 12 inches; and the action of these cups is to collect the water at distances of about 12 inches, so that there is a steady film of water continually passing down the tubes. A small annular space is left between the lower edge of the cup and the tube, for allowing the water to pass through. Several slots are made in the side of the cups, through which the water can still flow, even should the annular space become obstructed by sediment or dirt. The cups also act as tube scrapers by being moved up and down by hand.

In Figs. 5 and 6, Plate 41, is shown a brass tube which is now being introduced for evaporative condensers of the vertical kind. The tube has longitudinal corrugations drawn into it for the greater part of its length, giving 25 to 30 per cent. more surface than the plain tube. The ends are left plain for about 3 inches, to allow for jointing and expansion. Figs. 7 and 8 show the Row indented tube, as applied to evaporative condensers.

With the Fraser horizontal tube, Figs. 9 to 12, Plate 42, water is taken from a rectangular tank, and passes along a horizontal perforated or slotted galvanized-iron pipe immediately above the condenser tube. For further distribution on the lower tubes, a strip of galvanized iron extending the whole length is fixed on the under side of each tube by means of iron straps or brass spring-clips, Fig. 14. When fans are used with this kind of condenser, a curved trough is fixed under the lowest tube of each row, turning the water off into side tanks; this prevents it from dropping upon the fan blades, and also prevents the disturbance of the water on the face of the tubes.

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In the Ledward condenser the water distribution is carried out as shown in Figs. 16 and 17, Plate 42. A main pipe is laid at right angles to the nest of tubes, and is supplied with water from the circulating pump; from the main are led branches, one over each row. The branch pipes are about 2 inches diameter, and have $\frac{3}{8}$-inch holes drilled along their upper side, immediately over which are fitted deflecting caps, extending the whole length of the distributing pipes and resting upon them. The water is forced into the distributing pipes and out through the $\frac{3}{8}$-inch holes, where it impinges against the deflecting caps, which spread it over the intermediate spaces. It falls in a film over the uppermost tubes, where it is caught by the uppermost ribs; it then flows round over the surface of the tubes, and is collected again by the lower ribs, ready for distribution upon the remaining tubes. Fig. 13 shows a wrought-iron tube without corrugations.

Other methods of distributing the water over horizontal tubes are shown in Plate 43. Figs. 20 and 21 show a wooden trough, into which water is pumped. The inlet pipe should be laid in the bottom of the trough for the whole length, with holes on the under side, to prevent any commotion of the water, and insure an even flow over the taper sides. The trough should be arranged perfectly level, with plain sides A or with holes B or notches C at intervals as shown, one trough delivering over two tubes. Figs. 22 and 23 are enlarged views of the cast-iron tubes T. Figs. 24 and 25 show a V trough with notches at intervals, through which water passes. A similar trough, but perforated at the bottom, is shown in Figs. 26 and 27.

Jointing of Tubes, and Water Seal.—It is highly important that all joints should be substantially made and perfectly air-tight. In some vertical condensers both the upper and the lower ends of the tubes are connected to the steam-chambers by triangular jointing-plates, Figs. 28 and 29, Plate 44. Expansion is provided for by the tubes sliding through the packings. The plates are generally made to allow three tubes to pass through. The holes are countersunk on the under side, the steam chambers being correspondingly

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countersunk on the upper side, and a rubber ring is squeezed between the conical surfaces by a substantial bolt in the centre of the triangular plate, Fig. 29. A later arrangement does away entirely with the top triangular jointing-plate, the tubes being fixed at the top by having their upper ends expanded directly into the top steam-chamber, Fig. 28. For removing or replacing a leaky tube, bolted covers are provided on both top and bottom steam-chambers; and the cover immediately above the leaky tube is taken off for allowing the tube to be withdrawn. In designing therefore it should not be forgotten to allow sufficient head room for this purpose. The lower jointing-plates and steam-chamber have a rib about $\frac{1}{2}$ inch high all round the edge, as shown in Fig. 28; by this means the lower ends of the tubes are always covered with water, and any small leakages are prevented from destroying the vacuum. The upper ends of the tubes are covered by the head of water always in the top water-tank.

In the horizontal condensers, both ends of the tubes are fixed by being expanded into a substantial tube-plate. Should leaks occur at the tube ends, the covers may be taken off, and the leak made good with very little trouble. The inlet and outlet connections for the nest of tubes are both made in the steam chamber at one end, which is a fixture, while the steam chamber at the other end is free to expand upon suitable rollers arranged beneath it. In the Fraser condenser the ends of the tubes before they reach the tube plate pass through a rectangular box, Figs. 30, 31, and 32, which is open at the top and closed at the bottom, and is bolted against the tube plate with a water-tight joint. It is kept full of water by means of a small supply-pipe, Fig. 30, led from the distributing tank.

Description of various arrangements of Condensers.—In Figs. 33 and 34, Plate 45, are shown two views of a Ledward cast-iron condenser, suitable for about 150 H.P. It consists of a number of transversely corrugated horizontal tubes, connected together at the ends by U tubes and in the centre by ordinary flanges. The exhaust steam enters each vertical section through a branch from the main pipe A; it passes through the tubes in the direction of the arrows

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to the air-pump suction B, and thence in a condensed form through the air pump. The circulating water is pumped up through the pipe C into the horizontal pipe D at top, from which branches are led over each section of condenser tubes; the water overflows, and is circulated over the tubes as before described. It is then collected in the lower tank, where it finds an outlet through the pipe E to the suction of the circulating pump F, and is used again. The head of water in the cast-iron collecting tank is maintained at a constant level by means of a ball cock. The air and circulating pumps are here shown directly under the condenser.

In Figs. 35 and 36, Plate 46, is shown another arrangement of a Ledward condenser, which is working at the Chapel Street station of the Kensington and Knightsbridge Electric Light Co., London. It consists of two bays of the corrugated tubes. The exhaust main runs between the bays, and has branches to right and left, connecting with each section. The condensed steam passes into the return pipe at bottom, and is collected in a drain box, and thence flows through a pipe leading from the lower part of the box to the hot well. From the upper part of the drain box a pipe is carried up into a common main leading to the air-pump suction. Each bay is supplied with a main circulating-water delivery, connected directly with the circulating pump; distributing pipes from the main are led over each section. This condenser is at present working with engines using a total of 20,000 lbs. of steam per hour, and maintains a vacuum of 23 to 27 inches of mercury, depending on the temperature of the circulating water. The quantity of water circulated is from 20,000 to 30,000 gallons per hour. The tubes, shown in Fig. 18, Plate 42, are in 5 feet lengths and 5 inches internal diameter. There are two lengths of tube, together providing without the bends a total length of 10 feet actual cooling surface. The tubes are jointed together with asbestos sheet, soaked in boiled oil, which appears to make a suitable joint for this class of work. They can be easily removed for repair. The conductivity through them is slow; therefore a considerable cooling surface is necessary. The condenser may stand as shown in Plate 45, upon girders with a cast or wrought-iron tank below, generally about 2 feet deep; or sometimes

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over a brick sump finished inside with cement, as in Plate 46. Fans are not employed; the evaporated water is carried away by the current of air blowing round the condenser. The amount of radiating surface allowed is about 1 square foot for every 1¼ lb. of steam to be condensed per hour; and each tube 5 feet long condenses about 40 lbs. of steam per hour or 2 H.P.; or 8 lbs. of steam is condensed per hour per foot run of tube. The ground or roof space required varies; but the maximum may be taken at about 36 square feet per 40 H.P., that is about 0·9 square foot per H.P. A condenser—

for 100 H.P. would require about 90 sq. ft. ground space.
„ 500 „ „ „ „ 450 „ „ „ „
„ 1000 „ „ „ „ 900 „ „ „ „

Some interesting results were obtained by experiments with a condenser of this kind connected with two Willans engines of 350 H.P. The condenser was situated about 140 feet from the engines, and the total distance travelled by the exhaust steam from the engines to the air pump was 350 feet, causing a difference of about ¾ inch in the mercury gauge between these two points. It was also found that the engines could run and be maintained at full vacuum with a load of 100 H.P. without the use of any cooling water.

A similar condenser, Figs. 37 and 38, Plate 47, is in use with cast-iron tubes, which are plain with the exception of the thin fin cast along the under side to collect the water for distribution upon the lower tubes. The circulation of the steam is exactly the same as in the preceding example. More sections may easily be added to this and other kinds of horizontal condensers. The distribution of water over the tubes may be carried out by any of the methods shown in Plates 42 or 43. At a colliery some time ago a condenser of this kind was erected above the ground level, for condensing the steam from the engines, one of which works in the mine about 100 feet below the level of the condenser; and this arrangement is still working satisfactorily.

A Fraser condenser with horizontal wrought-iron tubes, for dealing with 40,000 lbs. of steam per hour, Figs. 39 and 40, Plate 48, has been erected at the generating station of the Waterloo and City

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Electric Railway. It is arranged in two bays, right and left of the main exhaust-pipe; and in each bay two sets of sections are arranged vertically one above the other; each bay is complete with distributing tanks and pipes. From the vertical continuation B of the main exhaust-pipe two inlet branches V_1 and V_2 are connected through valves to each set of the lower and upper sections, so that one half of the condenser may be shut off if required. At the top of the vertical continuation B is an automatic relief-valve, which may be kept open for any length of time by means of the lever and cord, in order to allow of an examination being made without interfering with the running of the engine non-condensing. The inlet branches V_1 and V_2 pass between the bays, and pipes are led from them to each section. The steam, on entering at the top of any section of the condenser through the inlet pipe, passes first through ten tubes, arranged in two vertical rows alongside each other, with five in each row; it next returns through a lower double row comprising eight tubes, goes forward again through the same number at a yet lower level, and finally passes to the air pump through the six lowest tubes, Fig. 39. The tubes are 3 inches diameter and about 18 feet long, and are of galvanized wrought-iron. The condensed-water outlet pipes JJ are arranged in a similar manner to the exhaust-steam inlet pipes BB. The inlet and outlet pipes are so arranged and jointed that any single one can be removed with only a few minutes' stoppage, or the whole section to which it is connected may be completely shut off. The water-distributing tanks RR are above the branch inlet steam-pipes V_1 and V_2, with perforated distributing pipes leading from them to immediately above each row of condenser tubes; a separate pipe from the circulating pump is led into each tank. The distributing pipes from the circulating pump have valves fitted to them, so that the circulating water may be shut off from either distributing tank. Underneath the whole condenser are water-collecting tanks and four fans. The latter are driven from the underside by a continuous rope working from a pulley on the shaft of an electric motor. Toothed bevel gearing has been tried for this purpose, but has not proved satisfactory with the speeds at which the motor shaft is run. The

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fans are 5½ feet diameter, and run at about 300 revolutions per minute; the cooling water is prevented from falling on their blades by the U troughs shown. The condenser is situated about 100 to 120 feet from the engines and about 150 feet from the air pump, measured along the lines of piping. The ground space occupied by the condenser is 1 square foot per 5 H.P. The automatic relief-valve shown in Fig. 61, Plate 56, consists of a cast-iron body, with a cast-iron valve having a fibre seating. The chamber above the valve seat is of sufficient depth to prevent the steam from spreading when issuing from the valve; and also to hold a sufficient quantity of water for effectually sealing the valve when closed, and preventing any air leakage inwards. Should any loss of water occur through leakage, a small supply pipe may be led into this chamber. Fig. 41, Plate 49, is a photograph of a Fraser horizontal condenser at Blackpool, showing water circulating over the tubes.

The Fraser vertical brass-tube rectangular condenser is shown in Figs. 42 and 43, Plate 50. Four pairs of rectangular chambers are connected by vertical brass tubes about 1¼ inch diameter, jointed in the method before described. Around the four top steam-chambers are tanks, through which the tubes pass, leaving a small annular space; through this the cooling water flows down the condensing tubes to the water tanks below. On each of the tubes is placed a set of the brass cups shown in Fig. 3, Plate 41. The steam enters at the top through the main exhaust-pipe, from which are taken branches to the four upper steam-chambers through the controlling valves shown. Outlet pipes with controlling valves are taken from each of the lower chambers into the main outlet pipe, and then direct to the air pump. The long upright vessel to the left in Fig. 42 is an air cooler, and simply deals with the hot air from the top steam-chambers. This apparatus was designed to condense for about 600 H.P.

The Fraser circular condenser, Fig. 44, Plate 51, has concentric rings of tubes jointed to top and bottom annular boxes, with a set of cups on each tube. The exhaust steam enters by two inlets at the bottom box, and is made to pass up and down the tubes by means of partition plates, and finally to the hot well through the pipes B.

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The air pump is connected to draw from the top box; and the other connections are also shown. Inside each tube is a spiral distributor, Fig. 15, Plate 42. The fan at bottom is 5 feet diameter, running at 400 revolutions per minute.

The Theisen circular evaporative condenser, which appears to have been the pioneer of the vertical brass-tube condensers working with fans in this country, is shown in Fig. 45, Plate 51. It consists of two annular steam-chambers connected by vertical brass tubes, which are arranged in radial rows of three, and are lapped round helically with wires, Fig. 1, Plate 41. Immediately below the top steam-chamber is a water-tank, through which the tubes pass; and another water-tank is fitted at bottom to collect the cooling water. The bottom water-tank was originally arranged below the bottom steam-chamber, and the tubes in that case were not submerged; but in later designs the bottoms of the tubes are completely covered, as shown in Fig. 45. The steam is taken in at the bottom, and after passing through the condenser tubes is taken out again at the bottom directly to the hot well. The pipe to the air-pump is taken from the top of the condenser, and the air pump then deals with air only, which is cooled before reaching the air pump. The fan or air propeller discharges air at right angles to the tubes. By the use of the fan it is said that the condensation of steam is increased 50 per cent. The fan is run at a low speed, about 80 revolutions per minute, because a greater speed has been found to disturb the cooling water on the surface of the tubes.

In connection with these condensers a supplementary condenser or cooler, Fig. 46, Plate 52, is sometimes used. It consists of a vertical cast-iron or steel vessel, filled with brass tubes. Any uncondensed steam or admixed air from the main condenser passes in at the top and down inside the tubes, as in an ordinary surface-condenser. Fresh cold water, which is used to make up the loss by evaporation in the main condenser, is passed through the cooler, and then delivered with the other circulating water into the top water-tank over the tubes. The final temperature of the air from the condenser is thus reduced lower than it otherwise would have been. It will be seen that in the main condenser the hot exhaust steam is always

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in contact with the hottest circulating water, and that in the cooler the hot air passing to the air pump is exposed last to the coldest temperature of the water passing through the cooler. The steam as it is condensed in the main condenser naturally falls, and the circulating water starting at the top gravitates to the bottom, where its temperature occasionally rises so high as to cause a loss of vacuum. The following are the temperatures of the steam at various pressures below the atmosphere :—

Vacuum in inches of Mercury .	0	11	18	22½	25	27½	28½	29	29½
Temperature of Steam . Fahr.	212°	190°	170°	150°	135°	112°	92°	72°	52°

A Theisen circular condenser without a fan is shown in Fig. 47, Plate 52, in which an upward current of air is induced by means of the iron chimney at the top of the casing surrounding the condenser. These condensers are also made in the rectangular form. The tubes are lapped with special fabric. In compiling Table 1 Messrs. D. Stewart and Co. of Glasgow, makers of the Theisen condenser, have taken 30 lbs. of steam per hour per I.H.P.

TABLE 1.—*Theisen Evaporative Condenser. Plate* 52.

Power of Engine . H.P.	75	100	150	200	300	400	500
Steam condensed per hour . . lbs.	2,250	3,000	4,500	6,000	9,000	12,000	15,000
Space required, square feet	40	40	56	72	72	110	110
Height . . . . feet	10	11	12	12	12	13	14
Condensing water per hour . . gallons	330	450	675	900	1,350	1,800	2,250
Total power required to work condenser H.P.	2	3	4	5	6	8	10

A minimum of one square foot of tube surface per 8 lbs. of steam condensed per hour is generally provided. In the supplementary cooler, Fig. 46, Plate 52, it is usual to allow one square foot of

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surface for 80 lbs. of steam per hour. A set of Theisen condensers at present working deals with 3,000 H.P.; it consists of four circular condensers. There are altogether eleven separate engines with thirty-one cylinders; one engine of 200 I.H.P. is 260 feet from the condenser and 130 feet from the air pump. A 12-inch centrifugal pump supplies the circulating water. A 16-H.P. engine drives this pump and fans, and an additional 15 H.P. is required for the air pump, which is 16 inches × 16 inches and is driven at 100 revolutions per minute; the 31 H.P. therefore is just over 1 per cent. of the total engine power.

The Wright condenser is vertical, and resembles those already described, the chief difference being in the method of distributing the cooling water over the surface of the tubes. In Plate 53 are shown two views of a Wright condenser suitable for about 500 H.P. It consists of four upper and four lower rectangular steam-chambers; the two chambers of each pair, forming one section of the condenser, are connected together by sixty brass tubes about 15 feet long by 2 inches diameter. Around these tubes is placed the distributing netting, Fig. 2, Plate 41. One such section contains about 500 square feet of cooling surface; and seven sections are allowed for about 1,000 H.P. The main exhaust-pipe rises vertically, with a relief valve on the top; just below the valve a swan-neck bend is led into the main inlet pipe A, from which are led four branches B, one to each upper steam-chamber. The steam passes into the condensing tubes, and may be made to pass up and down them again by the interposition of partition plates, till it reaches the lower steam-chamber and the condensed main C at the opposite lower corner; a connection is made from each steam-chamber to the condensed main. In the partitions are made holes for allowing the condensed steam to drain to the outlet, while the uncondensed steam passes up again through the tubes. The condensed steam may be taken direct to the air pump, or may pass through the cooler shown. Connection is also made to the cooler from the top of the condenser, in order to take away the hot air, thus reducing the final temperature in the condenser, and so preventing re-evaporation. For the water circulation a supply tank is fixed in any convenient position, a

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connection is made from it to the circulating pump, and a delivery pipe is carried up to the level of the top water-distributing tanks, whence branches S are led over into each tank; the water passing through annular spaces in the tank bottom flows down the tubes and wire netting. At the bottom it is collected in the lower receiving tanks, and flows through branches into a discharge main D leading to the circulating-water supply-tank. The fan of 5 feet diameter may be placed directly under the condenser; but in a condenser now being erected at Hastings it is placed at the top, and the shaft passing down through the condenser is driven by an electric motor.

Leading Water over Tubes.—With the vertical condenser some difficulty has been experienced in getting the water to start evenly down the tubes. An early method was to countersink the bottom of the water tank, Fig. 50, Plate 54; but it was found that the cup formed by the countersink soon became filled with solid matter which came over with the circulating water, so that the water could not get through at all. The countersink was then reversed, Fig. 51, which was a marked improvement. In the Wright condenser the annular outlet for the water is raised above the bottom of the tank by means of a lip, shown in Fig. 52, thus keeping back any obstruction in the bottom of the tank. A later arrangement is shown in Fig. 53, in which a brass bush is driven into the bottom of a cast-iron distributing-tank. But the tubes cannot always be depended on to keep a perfectly central position in relation to the holes in the tank. To remedy this a substantial conical cup was placed immediately below the tank, Fig. 54.

An evaporative condenser with horizontal tubes, which was erected by Sir Frederick Bramwell twenty-six years ago in Belvedere Road, London, is still at work producing a satisfactory vacuum. It is illustrated in Plate 55, and consists of eight sections, each containing 32 wrought-iron tubes of 1 inch diameter internally. The sections are divided into two parts, upper and lower, each having its own water-distributing trough. The troughs are supplied with water from an overhead tank, from which are led bends delivering into

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each trough. The exhaust steam enters through a pipe at the top right-hand corner, and passes into each section through flanged branches; the condensed steam is drawn off at the lower opposite corner by a similar pipe, which is connected with the air pump. A tank is fixed underneath to catch the circulating water. The ends of the tubes pass through the cast-iron tube-boxes, and each is jointed inside by means of an ordinary gland with a rubber joint and two bolts, as shown in Figs. 59 and 60, Plate 56. An enlarged view of the water-distributing trough is also shown in Figs. 57 and 58. The condensers are connected with a Watt beam-engine, indicating about 150 H.P.; the air and circulating pumps are worked from the beam.

A similar condenser by Messrs. John Kirkaldy, which is principally in use abroad, is shown in Plate 57. It consists as usual of two end boxes, into which the horizontal galvanized wrought-iron tubes are fixed by expanding their ends, Fig. 62. Opposite the end of each tube is a small gland-shaped cover in the end of the box, Fig. 63, for the purpose of facilitating the fixing of the tube end and examination of the joint. The water is distributed by means of a triangular V-shaped trough with holes drilled through the bottom. The condenser here shown is suitable for condensing 2,000 lbs. of steam per hour. Its height is 10 feet, its total length 12 feet, its width 5 feet, and it contains forty tubes. Such condensers weigh about 1 cwt. per 30 lbs. of steam condensed per hour.

The vertical cast-iron condenser shown in Plate 58 consists of two rows of vertical tubes S, connected at the top by bends, and leading from one horizontal pipe into another. A is the exhaust main, and B the air-pump suction-pipe for drawing off the condensed steam. The vertical tubes are 4 inches diameter. A cast-iron trough D is fixed across and above them, and immediately over each tube the trough is perforated with a hole, which allows the water to fall directly on the centre of the bend, whence it runs down the whole length of the tube to the cast-iron collecting tank F at bottom. The delivery pipe to and from the circulating pump is shown at E and C respectively. The whole apparatus is supported

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above the tank F. The vertical tubes are about $\frac{5}{16}$ inch thick, and the larger pipes $\frac{1}{2}$ inch to $\frac{5}{8}$ inch. In connection with this condenser some valuable experiments were made and recorded by Mr. Michael Longridge in 1892.* Table 2, and the diagram,

TABLE 2.—*Condenser with Vertical Cast-Iron Tubes. Plate* 58.

1	Date	1892	Sep. 12	Sep. 13
2	Weather		Wet	Fine
3	Barometer	ins.	29·8	29·5
4	Temperature of air	Fahr.	?	60°
5	External surface of condenser	sq. ft.	272	272
6	Duration of trial	minutes	99	115
7	Weight of steam condensed during trial	lbs.	800	800
8	Boiler pressure per square inch	lbs.	60	60
9	Weight of water in circulation, about	lbs.	1,830	1,830
10	Weight of fresh water added during trial	lbs.	600	640
11	Weight of water lifted by circulating pump	lbs.	11,200	?
12	Vacuum in condenser, per mercury gauge	ins.	23·36	24·1
13	Initial temperature of circulating water in distributing trough D	Fahr.	117·5°	113·9°
14	Final temperature of circulating water falling into collecting tank F	Fahr.	128·4°	125°
15	Temperature of supplementary fresh water from town main	Fahr.	58°	58°
16	Temperature of water in hot well	Fahr.	136·5°	131°
17	Weight of steam condensed per minute	lbs	8·08	6·95
18	Weight of circulating water delivered into distributing trough D per minute	lbs.	113·1	?
19	Weight of supplementary fresh water poured into collecting tank F per minute	lbs.	6·06	5·57
20	External surface of condenser per lb. of steam condensed per minute	sq. ft.	33·7	39·1
21	Volume displaced by air-pump bucket per minute (up strokes only), per lb. of steam condensed per minute	cub. ft.	2·5	2·9
22	Volume displaced by bucket of circulating pump per minute (up strokes only), per lb. of steam condensed per minute	cub. ft.	0·31	0·36

Fig. 66, Plate 58, are taken from his report, showing the temperature of the circulating water and of the air-pump discharge, with the weight of circulating water delivered over the tubes. This condenser was made by Messrs. Cooper and Grieg, Dundee. The conditions were unfavourable, owing to damp weather and the

* The Engine, Boiler, and Employers' Liability Insurance Co., Chief Engineer's Report for 1892.

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position of the overflow tanks. The tubes were coated with a thin scale outside, but were clean inside. It will be seen in line 7 of the Table that 800 lbs. of steam were condensed during the trial, and also that the make-up water in line 10 was 600 lbs. during the same time. Thus $\frac{3}{4}$ lb. of water was evaporated per lb. of steam condensed.

In a paper read by Mr. Row,* some interesting experiments were described, showing the value of air currents directed upon vertical condensing tubes with water passing over them. Figs. 67 and 68, Plate 59, represent the experimental apparatus used; and Table 3 shows the results of the tests. The plain-tube test was conducted with a tube shown in Fig. 68 before being indented. The steam, was admitted into the tube at the valve A, and the condensed water

TABLE 3.—*Tests with Plain and Indented Tube, and with Air Current. Plate* 59.

Description of Test.	No. 1. Plain Tube and Condensing Water only.	No. 2. Indented Tube and Condensing Water only.	No. 3. Indented Tube and Condensing Water, assisted with Air Current.
Time, one hour { commencement. .	10.45	12.0	3.0
Time, one hour { finish	11.45	1.0	4.0
Temperature of atmosphere . . .	65° F.	70° F.	64° F.
Temperature of condensing water in pan G and bucket G' . . .	133° F.	120° F.	115° F.
Temperature of condensed water at D	154° F.	155° F.	153° F.
Weight of condensing water evaporated . . . . . lbs.	10·62	27·00	50·0
Weight of steam condensed . lbs.	20·62	39·69	63·4
Evaporation ÷ Condensation, ratio	0·51	0·68	0·78
Vacuum per square inch . . lbs.	10	10	10

* Manchester Association of Engineers, Transactions 1897, page 57.

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dropping into the receiver B was drawn off at stated periods from the cock D. The vacuum was induced by the ejector C. The cooling water was raised by pumping, and allowed to trickle in a thin film from the pan F at top; the water not evaporated fell into the pan G and bucket G′ and was re-pumped. The test shown in Fig. 67 was conducted in a precisely similar way, with the addition of the casing H, through which an air current was induced by an ejector in the branch J. The plain tube in test 1 was 16 feet long, 1½ inch internal diameter, and No. 16 wire-gauge thick (0·065 inch). This was afterwards indented for tests 2 and 3 when it measured 14 feet 5¾ inches long. The total condensing surface exposed to the atmosphere was 8 square feet, including the surface in the pan G and receiver B. On the basis of test 3 with air current, deducting 25 per cent. from the result obtained under experiment and taking the condensing efficiency of indented copper as equal to 6 lbs. of steam per hour per square foot of surface, it is possible for an evaporative condenser for 200 H.P., allowing 20 lbs. of steam per H.P., to be enclosed in a casing 3½ feet square, standing 12 feet high. In these single-tube experiments, the air current in Fig. 67 was induced to pass the surface of the tube in a way that is not obtained in present practice. The fan, if placed at right angles to the tubes at the bottom, as shown at B in Fig. 78, Plate 61, would force the air against the opposite casing, almost entirely destroying the nature of the current; after which it would have to find its way at any angle past the tubes. It is doubtful whether a condenser of the size given above would be capable of dealing with 200 H.P. Two views of a Row evaporative condenser with fan are shown in Plate 60.

Design, Arrangement, and Efficiency of Fans, as applied to Evaporative Condensers.—It has been shown by experiment that, by the use of a current of air passing over the surface of a tube upon which water is running, the condensing efficiency can be increased by nearly 70 per cent. Taking full advantage of this 70 per cent. as equivalent to 41 per cent. reduction in surface, an

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evaporative condenser with vertical brass tubes should not require more surface than an ordinary surface-condenser, that is, about 2 square feet per I.H.P., though satisfactory results have not yet been obtained from this proportion. Various arrangements of fans are shown in Plate 61. Fig. 71 represents a tube exposed to the atmosphere, with a small propelling fan at the lower end; the tube might be enclosed, as in Figs. 72 or 73, without great loss of efficiency. These three arrangements would suggest that probably a freezing action would take place near the tube, due to the rapid evaporation of water caused by the air current. Fig. 74 shows a propelling fan working in the centre of a circular condenser with concentric rings of tubes. The fan may be arranged to exhaust the air from the top of the condenser, as in Fig. 75; but such an arrangement would have little advantage, if any, over the propelling method shown in Fig. 74. A propelling fan fixed directly under rectangular boxes, as shown in Fig. 76, is not so good as the same fan placed as in Fig. 74. A still inferior method is that shown in Fig. 77, in which the fan is arranged to propel the air horizontally below rectangular boxes. The propelling fan in Fig. 78 at B is also inefficient, while the design at A is not to be commended at all. The kind of condenser in most instances governs the arrangement of the fan. The efficiency of the fan itself is not considered here so much as its steam-condensing value. The examples given in Figs. 71, 72, and 73, are merely theoretical. The various arrangements shown in Figs. 74 to 78 are working in one or other of nearly all vertical evaporative condensers, and the efficiency of the apparatus is to a certain extent increased thereby in all. It is not advisable to use fans at all in horizontal condensers, and these should really be designed with sufficient surface to do without them. In a horizontal wrought-iron-tube condenser each square foot of surface should condense from 2 to 4 lbs. of steam per hour: that is, the condenser should have about 8 square feet per I.H.P. The value of a fan in increasing the hourly condensation under existing circumstances when working with vertical condensers cannot be taken at more than 20 per cent.; and this amount is often reduced to 10 per cent.

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or 5 per cent., or even lower. Where condensers are not designed to take the maximum load, fans are sometimes used to carry the engines over the maximum load. The style of fan that appears to find most favour for this class of work is one with blades such as could be laid on the surface of a cone, their backs being radially straight. Transversely the faces delivering the air are concave, with convex backs. The blades are set at an angle in the usual manner. Water should not be allowed to fall on the fan blades. The power required to drive the fans varies from 1 to 2 per cent. of the total engine-power, or sometimes more.

Conditions governing Design, Arrangement, and Maintenance of Evaporative Condensers.—It is important that ample means should be allowed for cleaning, especially as regards the outside surface of the tubes. One square foot of tube surface will evaporate half a gallon of water per hour: so that, if the water were only moderately hard, the amount of deposit in a year would be considerable. The circulating water itself should be kept clean. One method of removing hard scale from the tubes resembles that adopted in feed-water heaters: namely to stop the water in circulation, and to pass steam into the condenser, when the difference of expansion between the tube and the scale causes the latter to crack; it can then, as a rule, be easily removed by hand. The exhaust pipe may enter at either the top or the bottom of the condenser. It is generally made of mild steel plate $\frac{3}{16}$ to $\frac{1}{4}$ inch thick, with substantial faced flanges riveted to each end; and pipes 18 inches to 24 inches diameter are often erected in complete lengths 40 to 50 feet long. They should if possible have a fall towards the condenser; but if circumstances do not permit of this, they can be so arranged as to drain back into a chamber at the lowest point in the run, from which a pipe is led to the air pump. The outlet pipe from the bottom of the condenser is led with a fall direct to the air pump. But where the condenser is about 29 or 30 feet above the hot well, the pipe direct to the air pump may be dispensed with, and the condensed steam may drain through a pipe directly into the hot well; the air pump then deals only with the air from the top of

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the condenser, from which a much smaller pipe is led to the air pump. Between the condenser and the air pump is fixed a cooler, into which a spray of water is admitted as in an ordinary jet condenser, thus reducing the final temperature of the air.

Jointing and Testing.—All joints should be machined, and made even more carefully than steam joints. They may be made with rubber insertion, or asbestos, or asbestos soaked in boiled oil. When the tubes and condenser are erected, the whole should be tested under water pressure; and the pressure from a water main is usually sufficient for this purpose. On the occasion of starting a certain condenser, it was found that the vacuum could not be maintained. Examination was made of all the joints, and a few noticeable leaks were stopped; but still it was far from being tight, and continued to give trouble. At last it was decided to test the whole apparatus under water pressure, when the leaks were soon detected and made good, with the result that the required vacuum was obtained. In another instance where air leakage caused trouble, the feed-pumps were abnormally large for the boilers they were feeding, and pumped a considerable amount of air along with the water. It is desirable to place the condenser as near the engine as possible, in order to save cost of pipes, bends, &c., and also to reduce the risk of leakage. Condensers are working satisfactorily at a distance from the engines of 100 to 120 feet, and in some instances even more. The horizontal condensers should be exposed as much as possible; the best place is upon the roof. Care should also be taken however, especially in the plain-tube or wrought-iron horizontal condensers, to shield the tubes from the direct action of the wind, which the author has observed to sweep a portion of the nest of tubes quite devoid of circulating water. Vertical condensers with fans and without casing are invariably placed in the open. The practice of connecting several large engines to one condenser should be discouraged; but where the engines are small, they may be connected into one exhaust main, with controlling valves to shut off each as required. Where the engine room is being extended or newly built, the roof on which the condenser is

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placed should be flat and made watertight, and in one or two places sloped to a gully covered by a wire grating; connections are made from the gullies to the circulating pump. The condenser is built upon girders, and the circulating water after passing over all the tubes should be allowed a fall of 3 or 4 feet before it reaches the roof. This is an effective means of lowering the temperature of the cooling water; or a wrought or cast-iron tank of ample area and about 2 feet deep may be placed under the condenser. The arrangement of piping is shown in Plate 62. Duplicate condensers are not required, the steam being exhausted into the atmosphere while any slight repair is being made good.

Cost and Choice of Condenser.—The average cost of evaporative condensers is about 20*s.* per H.P., exclusive of the cost of air and circulating pumps and connections. Compared with jet condensers, the cost is no doubt greater; but including reservoir construction and cooling apparatus, the evaporative condenser is more economical. Some judgment must be used when selecting a condenser for any particular purpose. When ample room and good foundations are at hand, and the condenser has to be worked under rough conditions, the cast-iron condenser is more suitable and cheaper than other kinds. The horizontal condenser, fitted with wrought-iron or copper tubes, is far more efficient weight for weight, and occupies much less room than the cast-iron condenser. The scale can be more easily removed from such tubes than from cast-iron tubes. Greater success has been obtained with a distribution of water over the tubes in the horizontal condenser than in the vertical; and when space permits, the former is recommended.

The vertical brass-tube condenser with fan is adopted when space is limited. Condensers of this kind do not at present give the results which were expected, too much value having been attributed to the fans; but if ample cooling surface is allowed, the author considers that no difficulty whatever should be experienced with them.

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Circulating Pumps.—Various kinds of pumps are used; that which seems to find most favour is the ordinary centrifugal pump.

Air Pumps.—It is important that an efficient air pump should be used. The size designed for an ordinary surface condenser would be generally suitable for an evaporative condenser of the same capacity. Various designs are employed, including the ordinary marine air pumps with three sets of valves, the single-valve pump on the Edwards plan, and displacement pumps similar to those used with jet condensers. In some cases three barrels are arranged alongside of one another, and are driven by a three-throw crank, coupled directly to an electric motor running from 100 to 200 revolutions per minute. The same design of pump is sometimes driven by a high-speed motor running at 1,000 to 1,200 revolutions per minute; connection is then made to the pump shaft by a worm and worm-wheel running in a bath of oil, and reducing the speed to 100 or 120 revolutions on the pump shaft. With the important subject of air pumps the author is able to deal only in a brief manner, while cooling towers and reservoirs have been purposely omitted.

Discussion.

The PRESIDENT called upon the Members to give Mr. Oldham their cordial thanks for the labour he had bestowed upon the preparation of this interesting and extended description of evaporative condensers.

Mr. OLDHAM assured the Members he fully appreciated their cordial reception of the paper. In addition to the condensing tubes described therein, he should like to draw attention to the new construction of Kynoch tube shown in Figs. 81 and 82, Plate 63, which was approximately heart-shaped in cross section, and had small

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(Mr. Oldham.)

circumferential ribs cast upon it, or drawn upon it if it was made of steel, for collecting the water in between the ribs, and giving an even flow over the whole length of the tube. When the tube was designed, it was arranged to be made in steel, which would of course have to be rolled to a special section with the ribs upon it. The tube itself was rolled into the heart-shaped section, the two free ends were brought together and riveted up, with a caulking strip in between. The flanges would have to be formed on the ends of each length of tube; and from this mode of construction he feared considerable leakage would result at the flanged joints and rivets. In Figs. 81 and 82 the tube was shown as made in cast-iron, which he thought would be less likely to cause trouble than the built-up steel tube. The cooling water was collected in the longitudinal depression or recess, which ran all along the top of the tube, and from which the water flowed slowly over the tube in a thin film. This section of tube he thought would have a slight advantage over a round tube. It collected the water on the top; and if it was placed perfectly level, the water would flow over quite evenly down upon the next tube below.

Mr. BRYAN DONKIN, Member of Council, pointed out that the title "evaporative condensers" did not necessarily imply that it was steam which was to be condensed. There were now so many gases which could be condensed, and it seemed probable that in future years there would be so many more, that he thought it should be stated what vapour it was intended to use in the evaporative condenser. It seemed to him therefore that it might be preferable to call these evaporative condensers "air and water condensers for steam." Surface condensers of this kind seemed to be coming more and more into use; and it was therefore interesting to have the experiments which had been given in the paper, particularly those made with the induced or forced draught of the fans (pages 202–203).

From his experience of open-air condensers in towns, the surfaces of the tubes both inside and outside were everywhere largely exposed to dirty water, and the same water was often used over and over again. To this question of dirt he thought sufficient

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attention had not been paid: dirt on the tubes, and dirt in the circulating water. It was preferable in his opinion to have all the tubes cylindrical, so that they could be cleaned readily, not only inside but out; and arrangements should be made for this to be done in the easiest manner. Flanges he thought were most important for making the joints, so that the whole could be taken to pieces at certain intervals when necessary, and the tubes looked through from end to end. Sometimes in London, with its dirty atmosphere, as much as half an inch thickness of dirt had been found outside the tubes, and also a considerable oily and greasy deposit inside: so that any projections or depressions on the surface of the tubes, whether inside or outside, he was afraid would be only places for accumulating the deposits of dirt. As the circulating water should touch the whole external surface of the condenser tubes, the success of any condenser was greatly dependent upon the water being kept clean, as carefully pointed out in page 204. The arrangements should be such that the water should run as nearly as possible over the whole surface; and on this account the horizontal arrangement of tubes would probably be rather better than the vertical.

As to the kind of metal to be used for the tubes, he was afraid the metal itself had but little to do with the efficiency of the condenser. The rate of transmission of heat through the metal was hardly ever of consequence, because it was chiefly the dirt outside and the dirt inside that had to be penetrated by the heat, just as in boilers and other heating apparatus. The dirt acted as a great retarder to heat transmission; and though the metal did its best when it got a chance, yet unfortunately it seldom did get one.

The joints were a vital part of the apparatus. In his opinion flanges ought always to be used, and always machined; otherwise some leakage generally took place, and the vacuum was more or less spoilt. It was easy to arrange the condenser tubes conveniently for testing under pressure, so that, by simply opening one cock and shutting another, water could be admitted inside the tubes while the engine was standing, and the tubes thus be tested daily or weekly.

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(Mr. Bryan Donkin.)

Air propellers were no doubt valuable for improving the condensation; but data were wanted as to the power required to drive them. In some instances the extent of the cooling surface was given in the paper; but in several it had not been stated, and if in these it could be added it would be much appreciated. Also the actual vacuum and the height of the barometer should be given in each particular case. The weather too was an important consideration: it was desirable to know whether there was a gale of wind, or no wind at all, or a thick fog, such as often occurred in London. The experiments on the Row condenser, given in Table 3, he was afraid had been made with the tubes perfectly clean, which would not be their condition in practice. In all experiments it was desirable that the actual condition of the tube surfaces, both inside and out, should be carefully noted. A condenser in America, of which he had read, had horizontal cylindrical tubes placed in shallow troughs of water; that seemed to him to be a good arrangement. He enquired whether any applications had been made of the plan of spraying the water upon the tubes under pressure.

Mr. MICHAEL LONGRIDGE considered the subject treated in the paper was both important and interesting. It was important because the apparatus described enabled any non-condensing engine to be converted into a condensing engine with profit, provided from 30 to 40 per cent. of the cost of coal and water for the non-condensing engine would pay maintenance and interest on the outlay for the condenser. The subject was interesting, because he was sure many engineers like himself desired to know more about it. Only ten years ago he had been asked to reduce the coal bill in a mill near Dundee, which was driven by a non-condensing engine. As there was too little water to supply a jet condenser, he had suggested an evaporative condenser. The suggestion was not entertained, because neither the mill-owner nor his friends had ever seen or heard of one. Their decision he could not say had been altogether unsatisfactory to himself; for the designing of the condenser, if it had been decided upon, would have caused him no little anxiety, owing to the want of reliable information as to the quantity of surface required and the

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proper arrangement of the details. Among the figures which he had collected at the time were some relating to a condenser made of pairs of vertical cast-iron cylinders, one fixed inside the other, with an annular space between the two, in which the steam was condensed by water flowing over the external surfaces. The outer cylinders were about 3½ feet external diameter and 12 feet high, and each pair had about 250 square feet of surface. There were sixteen pairs of cylinders, or 4,000 square feet of wetted surface, for an engine developing about 400 I.H.P., giving 10 square feet per indicated horse-power; or assuming, as in the paper, one horse-power to require 20 lbs. of steam per hour, which would probably be nearly correct in that instance, there were 30 square feet of surface per lb. of steam condensed per minute. As to the quantity of water in circulation, or the loss of water by evaporation and dispersion by the wind, he had been unable to get any information. In another instance he had been told that 5 square feet per indicated horse-power was the proper amount of surface; this was equivalent to 15 square feet per lb. of steam condensed per minute. In a third instance as much as 60 square feet of surface per lb. of steam condensed per minute had been stated to be necessary. Such was the kind of information he had been able to gather then; and he thought that even now engineers had not much that was more definite to guide them. The only published figures he had found were contained in papers by Mr. Tom Westgarth and Mr. Henry Davey: the first read in March 1894 at Middlesbrough to the Cleveland Institution of Engineers (Proceedings 1893–4, page 120); the second read before the machinery section at the engineering conference of the Institution of Civil Engineers in 1897 (Proceedings, vol. 130, page 195). Mr. Westgarth quoted the experience of Mr. Henry Cochrane at the Ormesby Iron Works, Middlesbrough, with cylindrical condensers of the kind already mentioned, as showing that 10 square feet of surface with 400 lbs. of water flowing over them per hour sufficed for one I.H.P., and that with this large supply of water the loss by evaporation was about 4 lbs. per I.H.P. per hour. Assuming the engines to have used 20 lbs. of steam per hour per I.H.P., these figures were equivalent to 30 square feet of

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(Mr. Michael Longridge.)

surface per lb. of steam condensed per minute, to 20 lbs. of water passing over the tubes per lb. of steam condensed, and to a loss by evaporation of 0·2 lb. of water per lb. of steam condensed. Mr. Westgarth's own opinion (page 122) was that for a triple-expansion or other good compound engine 10 square feet of cooling surface per I.H.P. would be ample, with a moderate supply of cold water; and that the loss by evaporation would be somewhat less than the weight of steam condensed. As such an engine would use from 12 to 15 lbs. of steam per I.H.P. per hour, the above surface would be equivalent to from 50 to 40 square feet of surface per lb. of steam condensed per minute. On the other hand Mr. Davey recommended 6 square feet per lb. of steam condensed per minute, supplemented by a small surface-condenser with about one square foot of surface per lb. of steam condensed per minute; and a circulation of 20 lbs. of water per lb. of steam. These figures appeared to have been derived from Mr. Theisen, as they agreed so nearly with those given in page 196 of the paper. Here again was a great diversity of opinion resting upon only a small basis of exact observation.

In order to design an evaporative condenser with confidence of success, it was necessary to know not merely the surfaces which had been applied per indicated horse-power with more or less success, but also the surfaces which had sufficed to condense known quantities of steam with known quantities of water at known temperatures; and further to know how the surfaces, the vacuum obtained, and the losses by evaporation depended upon the capacities of the storage tank and circulating pump, and upon the temperature of the cooling water. On these points the paper gave little information. From the statement in page 192—that in the Ledward condenser described in page 191 about 1 square foot of radiating surface was allowed for every 1¼ lb. of steam to be condensed per hour, and that each tube 5 feet long condensed about 40 lbs. per hour—it could be inferred that each tube had about 32 square feet of surface; in Figs. 35 and 36, Plate 45, there were shown 360 tubes of 5 feet length; hence the condenser here shown would have about 11,520 square feet of surface, or 34·6 square feet of surface per lb. of steam condensed per minute; and it was stated that from 10 to 15 lbs. of

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water were circulated per lb. of steam; but no information was given as to the duration of the full-power runs, the tank capacity, the temperature attained by the water, or the loss of water by evaporation. Again by calculation from Figs. 39 and 40, Plate 48, and from the figures given in page 193, it could be ascertained that the Fraser condenser there described had nearly 9,050 square feet of surface or nearly 13½ square feet per lb. of steam condensed per minute, but here the evaporation was accelerated by fans; no other information was supplied. The Theisen condenser (page 196) appeared to have 7½ square feet of surface per lb. of steam condensed per minute, being supplemented by a small surface-condenser with about ¾ square foot per lb. condensed per minute, and was said to require about 1½ lb. of fresh condensing water per lb. of steam condensed; but there was no information as to the efficiency of the plan. The Wright condenser (page 197) was said to have 3½ square feet of surface per I.H.P., equivalent to 10½ square feet per lb. of steam condensed per minute, assuming a consumption of 20 lbs. of steam per I.H.P. per hour; but nothing was said about the results obtained.

The experiments referred to in page 199 he had been able to make through the kindness of Messrs. Whyte and Cooper of Dundee in altering pipes and connections. These experiments had been fully described in his report for 1892, to which allusion had been made; and his only object in now referring to them was to guard against a misapprehension which might arise from the figures quoted in Table 2, (page 200). It was there stated (line 9) that the storage tank F for the circulating water, Figs. 64 and 65, Plate 58, had a capacity of 1,830 lbs., or about 230 lbs. per lb. of steam condensed per minute. In the original report from which the figures were taken it had been pointed out that, owing to the alterations made in the arrangement of the circulating pipes for the purpose of the experiment, the discharge pipe C from the tank to the circulating pump was connected more than half way up the side of the tank: so that something like half the water in the tank was dead water, and the actual capacity of the tank was probably only about 115 lbs. instead of 230 lbs. per lb. of steam condensed per minute.

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(Mr. Michael Longridge.)

Incidentally to an engine trial, he had been able to make some observations upon another condenser of similar design. Although the figures, which were also contained in his report for 1892 (page 69), were not so complete as those quoted in Table 2, they might nevertheless be of some use, and were therefore given in Table 4. The condenser consisted of 80 vertical cast-iron tubes, having 1,170 square feet of surface. The capacity of the storage tank for the circulating water was 40,000 lbs. The engine indicated an average of 75 H.P.

In another instance he had provided 2,000 square feet of surface and a condensing-tank capacity of about 17,500 lbs. for a compound engine driving a saw mill with a boiler pressure of 120 lbs. per square inch. At present the engine was lightly loaded, the power varying throughout the day between 60 and 100 I.H.P. The steam used was probably from 16 to 25 lbs. per minute, according to the load. Though he had made no observations on this condenser, he referred to it for two reasons: firstly, because he was told that in cold weather it could be worked without any water, when the load was light, say from 60 to 80 I.H.P.; and secondly, because the water from the hot well, instead of being returned to the boiler, was pumped into the condensing tank. This was the only fresh water used, and it was more than sufficient to replace that lost by evaporation, since a fair proportion of it ran to waste by the overflow. The condensed steam was not returned to the boiler on account of the grease which came with it from the cylinders. From the information he had received about this condenser it would appear that in cold weather a condenser would work without water if its surface were about 125 square feet per lb. of steam condensed per minute.

So far as his own experience went, he should say that with water from 35 to 40 square feet of surface were required per lb. of steam condensed per minute. Whether this extent of surface could be reduced by using brass tubes, corrugated tubes, indented tubes, or any of the other devices mentioned in the paper, or even to any material extent by fans, he greatly doubted; and he feared that condensers with such small surfaces as recommended by Theisen and

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TABLE 4.—*Condenser with Vertical Cast-Iron Tubes.*

Date	1892	Sep. 7	Sep. 9	Sep. 14	Sep. 14	Sep. 15
Duration of experiment	minutes	81	89	139	116	133
Steam sent to condenser per minute	lbs.	24·6	26·8	25·7	20·6	22·8
Vacuum in condenser, per mercury gauge	inches	13·4	11·3	13·4	13·7	13·6
Initial temperature of circulating water	Fahr.	89	94	92	87	88
Final " " "	Fahr.	92	104	103	98	105
Mean " " "	Fahr.	90·5	99	97·5	92·5	96·5
Temperature of water in hot well	Fahr.	108	115	112·5	105	107
Mean difference of temperature inside and outside condenser	Fahr.	17·5	16	15	12·5	10·5
Condensing surface per lb. of steam condensed per minute	sq. ft.	45·7	43·6	45·5	57	51·4
Heat sent to condenser per hour	B.Th.U.	22,816	23,126	21,556	21,566	22,036
Heat transmitted per hour per square foot of condensing surface	B.Th.U.	19·5	19·8	18·4	18·4	18·9
Heat transmitted per hour per square foot of condensing surface per degree of mean difference of temp.	B.Th.U.	1·1	1·2	1·2	1·5	1·8

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(Mr. Michael Longridge.)

Wright would prove unsuccessful. If the figures given in Table 3 (page 201) were to be depended on, the Row indented tube certainly promised some success; but he was not at all satisfied that the figures were to be depended on, because the vacuum was obtained by the induction of a steam jet, and it was not clear that some of the steam which issued from the jet did not come from the inside of the condensing tube.

He could not see how spiral deflectors inside the condensing tubes, or circulation through them in series instead of in parallel, could increase the transmission of heat. The theory of an uncondensed core was unsupported by any evidence; and the device of a counter current could not be applied, because the condensed steam inside the tubes and the water outside must both alike flow downwards. The position of the steam inlet however he thought might affect the efficiency of the condensing surface. The inlet ought in his opinion to be at the bottom of the condenser, as in Fig. 64, Plate 58, so that the oil and water which entered the condenser in no inconsiderable quantity with the steam, particularly when the exhaust pipe was long, might not be carried over the whole internal surface of the tubes; for the thicker and more extensive the coating of water upon this surface, the less efficient would the surface be in condensing the steam.

It had been mentioned by Mr. Donkin (page 209) that a considerable oily and greasy deposit had sometimes been found inside the condensing tubes. This however had not been his own experience. The condenser referred to in Table 2 (page 200) was clean inside when tested, though it had been in daily use for two years previously. Only last Saturday (22nd April) he had taken some of the bends off the ends of the tubes in a Ledward condenser which had been at work for five years, and had found no oil or grease inside. He had also asked Messrs. Douglas and Grant of Kirkcaldy to examine the inside of another condenser which had been at work in their neighbourhood for seven years, and they had reported that they had found no oil. It might indeed, he thought, be asserted as a fact that the oil from the cylinders was not deposited at all inside the condensing tubes, but was carried through them along with the

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water which entered with the steam. It was generally supposed, and he had even heard it stated in evidence as a fact, that the oil which entered the main steam-pipe or valve chest of a steam engine from a sight-feed lubricator became incorporated with the steam in a fine spray or minute state of subdivision, converting the steam itself into a lubricant. But from what he had seen of difficulties in lubricating slide valves he was convinced that no such incorporation with the steam took place, but that the oil was carried into the cylinder and out of it upon the water which was always present with the steam; and if this oily water entered an evaporative condenser at the bottom, as it ought to do, it would never get into the tubes at all. This suggested a question about the arrangement of the ordinary surface-condenser. Generally the water passed through the inside of the tubes, the steam entered at the top, and after condensation was drawn off from the bottom; and although a certain proportion of the oil brought in with the steam was carried through to the boiler unless stopped by a special filter, a considerable proportion remained in the condenser, particularly upon the tubes just under the steam inlet; in both places the oil was inconvenient. Would it not then be better to let the exhaust pipe discharge into a well at the bottom of the condenser, as sketched in Figs. 84 and 85, Plate 64? or into a large separator before entering the condenser at the top? so that the water and oil brought in with the exhaust steam might be collected in the well or separator, and be removed by a special pump. Such an arrangement he was satisfied would keep both boiler and condenser almost if not altogether free from oil.

He should be glad to know if any trial had ever been made of a wet blanket sheathing upon the tubes of an evaporative condenser. It seemed possible that such a covering would permit the use of a much stronger air-current than could be employed where the water simply ran down or over the tubes.

Mr. Leonard Andrews said the Wright evaporative condenser shown in Plate 53, or one much like it, had been in use in the electric-light station at Hastings for about twelve months, during which time many experiments had been made with it. No entirely

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(Mr. Leonard Andrews.)

satisfactory results had yet been obtained. As at first arranged, all the tubes, according to electrical phraseology, were in parallel; that is, the exhaust steam came in at the top, and passed down through the whole of the vertical brass tubes simultaneously in parallel currents, and the condensed water was taken out through the bottom chamber and the air cooler. Although the condenser was designed to evaporate 15,000 lbs. of water per hour, it was found that it evaporated only 6,000 lbs., and the vacuum was only about 15 inches of mercury. The area of the condensing surface was about 2,000 square feet. It was suggested at the time that the only way to get any better results from the tubes in parallel would be to increase the surface of the condenser by adding extra nests of tubes; but as he had found that a large number of tubes were quite cool even at the time of the heavy load, he concluded that to put more tubes in would be only to increase the number of cold tubes. It appeared that, as soon as the engine began working, the steam started going down certain of the tubes, and then stuck to those particular tubes for the remainder of the working, and would not go through the rest of the tubes, which consequently remained cold. Apparently the steam formed a partial vacuum in the tubes which it first entered, and thereby drew in more steam after it into these same tubes: so that certain of the tubes did all the work, while the others did nothing. It had therefore occurred to him that possibly by putting the tubes in series, and thereby crowding the steam through them all, a better result would be obtained. In the first instance only two bays or nests of tubes were tried in series: that is, the steam was brought down through the first nest and taken up again through the second, and thence to the air pump. That gave a somewhat better result. The plan was then tried of putting the whole four nests of tubes in series: the inlet for the exhaust steam was made at the top, and the steam passed down through the first nest, up through the second, down through the third, and up through the fourth, from the top of which a pipe led off to the air pump, while the water was drawn off from the bottom of all four nests. With this arrangement much more satisfactory results were obtained: the vacuum at the air pump was 23 inches, while about 15,000 lbs. of water was being

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condensed per hour, which was the quantity the condenser was intended to condense. As no saving of steam was effected the first night, the engines were indicated to see what vacuum they had, and it was found to be only 3½ to 4 inches at the engines, although it was 23 inches at the air pump. A number of cocks were then put on at various points, by means of which it was found that at the tops of the bays in the centre, that is the second and third bays, a vacuum of about 12 inches was obtained, while at the top of the first bay it was only 3½ to 4 inches, the same as at the engines. Further investigation showed that this was due to the water having got up into the tubes, owing to the bottom boxes not being properly drained. A difficulty was experienced in draining the water away from the bottom of the tubes; for the proper working of the condenser it ought of course to be drained out from every one of the tubes. It had first been tried to accomplish this object by taking the bottom ends of the tubes in each bay into a box with a water seal at the bottom, and drawing off from beyond the seal to the air pump. An attendant had then to be stationed there, to keep the water level just the right height above the seal; because if the water got too low, the steam simply rushed through from box to box, blowing through the seal; while if the water got too high in the boxes, the vacuum immediately drew it up into the tubes, and it remained there for the rest of the working. The steam itself was sucked up through the tubes, notwithstanding the water in them, and apparently kept on condensing, and the condensed water kept on coming down into the bottom boxes. Thus the vacuum of only 3½ to 4 inches was maintained at the exhaust-steam inlet, while at the same time the vacuum at the air pump was maintained at 23 inches. The difficulty was eventually got over by the method suggested in page 204, namely that, if the condensers were 30 feet or more above the air pump, as those at Hastings were, the condensed water should run down a pipe direct to the hot well, instead of to the air pump. Accordingly from each of the boxes at the bottom of the condensing tubes a separate pipe had been led down directly into the hot well, and it was now found that the water in these descending pipes exactly balanced the vacuum: in other words, when a high vacuum

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(Mr. Leonard Andrews.)

was obtained, the water was drawn up from the hot well into these drain-pipes; and as fast as more water was condensed in the condenser, an equal quantity just ran out from these drain-pipes, and the water in them balanced itself automatically. As further suggested in page 205, a jet or spray of cold water was next admitted into the cooler, Plate 53, and a pretty good vacuum was thereby obtained at the engines. The only thing was that, while there was about 20 inches vacuum at the air pump, there was only about 12 inches at the top part of the condenser and at the engines. These facts he obtained only two or three evenings ago, and he had not come to any conclusion upon them yet. What he wanted to know was what this difference of vacuum between the two ends of the condenser was due to: because he did not see how any water could possibly stay in the condensing tubes, now that each of the bottom boxes was drained directly into the hot well, as just described. The difference of vacuum could not therefore be due to water throttling the passage through the tubes; and he thought the tubes themselves were not too small. The air pipe to the cooler and air pump was three inches diameter, and seemed large enough to take off all the hot air. The only theory he had about it at present was that the hot air endeavoured to rise from the hot well to the top of the condenser, that is, through a height of about 35 feet, and that consequently 8 or 9 inches of vacuum was expended in sucking the air down against its tendency to rise. Perhaps some of the members might be able to suggest some other explanation, and what should be done to remedy the defect of vacuum at the engines.

A fan was fixed on the condenser, and was originally arranged at the top, as shown in Plate 53, but without any hood over the top of the condenser. It was found that the working of the fan did not make the slightest difference in the condensation; and it was thought possible that if a hood was put over the top it might make a difference. A great deal of expense was therefore incurred in encasing the top of the condenser over the edges down to the bottom of the water-distributing tanks, so that the air discharged by the fan had to be drawn through the spaces between the condensing tubes. It was still found however that the running of the fan made absolutely

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no difference at all in the condensation. It was tried on two or three occasions, first a whole hour with the fan, and then an hour without the fan, on the same evening, so that the atmospheric conditions should not vary; but apparently it made absolutely no difference at all.

In page 204 it was recommended that horizontal condensers should be placed in a good position; and it appeared to him that the same recommendation applied equally to vertical-tube condensers. At Hastings the condenser was on the roof of a high building, and stood right out beyond everything else, excepting only where it was shielded from the wind by the chimney stack. It was put up by the side of the stack; and when the wind was in the direction from which the condenser was just sheltered by the stack, nothing like such good condensation was obtained as when the wind was blowing from any other direction.

Mr. HENRY B. SPENCER thought that, although the paper dealt only with evaporative condensers, and not with the whole question of condensation with a limited supply of water, it might be of interest if a reference were made to an alternative plan, in which the condensation of the steam was separated from the dissipation of the heat into the atmosphere, in contrast with the combined action of the evaporative condenser. In the past no doubt the evaporative condenser had been handicapped by the circumstance referred to by Mr. Longridge (page 210), that there had been so few records of its performance. The difficulties which had been experienced seemed to be due to the fact that sufficient cooling surface had not been allowed. On the Continent he believed there were a number of evaporative condensers doing good work, but in which a considerably larger surface was generally allowed than in this country. Another circumstance which had made a difference was that in this country the atmosphere was not generally so favourable to evaporation as it was on the Continent or in America. The average humidity of the atmosphere was much greater in England than in most parts of the Continent or America. In Fig. 83, Plate 63, was shown the Klein water cooler, with which he was best acquainted, and

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(Mr. Henry B. Spencer.)

in which the cooling of the condensing water was kept entirely distinct from the condensation of the steam. E was the exhaust pipe from the engine to the jet condenser J, from which the discharged water passed along the pipe D to a trough T inside the base of the wooden tower W. Thence it fell upon the upper ends of a set of slightly inclined slats or shelves S, presenting an extended surface, down which it trickled in thin films to the lower ends. An upward draught was induced by the tower; the air came in at A, passed through the nest of shelves in close contact with the thin films of water, and escaped up the tower. From the shelves the water fell into a tank K, and was thence drawn again through the pipe I into the jet condenser J. The advantages of this plan over the evaporative condenser seemed to him to be, in the first place, that it enabled any ordinary condenser to be used, of which the action was much simpler than that of an evaporative condenser, and was also much better understood. In the next place the cooling, which was a different problem from maintaining a vacuum, could be dealt with as an entirely separate affair; the cooling surfaces could be packed much more closely together, a much larger surface for dissipating the heat could be allowed, and the surface could be made of much less expensive material. All the surface in the cooler was external; there was no question of transmission of heat through metal. The difficulty of deposit or scale was to a great extent overcome; there was no trouble from scale in the condenser, whether it was a surface condenser or a jet condenser. The temperature of the water was not raised sufficiently to cause the formation of scale; and even if dirt did accumulate on the surface of the cooler, it could affect its cooling efficiency only by choking up the spaces between the shelves. These however were arranged so that they could be easily cleaned. To other plans of cooling it was often an objection that extra power was required to work them; but for the cooler shown in Fig. 83, of which there were several working satisfactorily in England, no extra power at all was required. The vacuum in the condenser drew the water up from a depth of 8 or 10 feet; and then the water and condensed steam from the condenser were delivered by the air pump to the cooler. There was no head of water on the delivery valves

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of the air pump, so that the vacuum was not interfered with thereby. This arrangement was not possible in all places. The disability attending a situation which was much cramped for space had to be paid for by expending more power to get the cooling required; by increasing the power and the height to which the water from the condenser was lifted, the cooling effect could be increased to almost any extent. On the other hand, if the power was to be kept down, more space must be allowed in which to do the cooling. The same condition applied also to evaporative condensers. In connection with the Klein cooler the object had always been as far as possible to avoid the use of fans. These could be avoided if the necessary space could be allowed; and then there was no expenditure of power except what might be necessary to raise the water to varying heights in the tower. It was not raised at all in the particular instance illustrated in Fig. 83, but was delivered to the base of the tower. In other arrangements it was raised to a height of from 16 to 25 feet, and trickled down over a succession of bars, laths, or grates, into the well at bottom. It was a sign of the times, he thought, that water-cooling arrangements were now finding favour in various works, in preference to evaporative condensers; and he trusted the hopes entertained of water cooling would be fully justified by the results, as he believed they would be.

Mr. C. J. BARLEY, having designed and erected the Ledward evaporative condenser and machinery at the Knightsbridge electric-lighting station, mentioned that one important point was the arrangement for separating the oil out of the condensed water. This was one of the difficulties in condensing; and in many instances where condensation was not adopted, it was because of the fear of the oil getting into the boilers. Ordinarily the only thing to do was to filter; and that was a troublesome process. At Knightsbridge there was a large separator in the main exhaust-pipe, between the engines and the condenser. It acted on the same principle as a steam separator between the boiler and the high-pressure cylinder. It threw down all the free oil, and the emulsion of oil and water which was drawn out of the engines. Good hydro-carbon cylinder-

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(Mr. C. J. Barley.)

oil could not exist as a vapour at exhaust temperature. The dried exhaust steam only was then taken up into the evaporative condenser situated overhead; and the clean condensed water was taken from the condenser direct by a barometric pipe to the hot well, which was about 36 feet below the condenser bottom. The samples of the water he now exhibited had been taken from the condenser under various conditions of working. One of them had been taken with a load of 1,200 I.H.P. on the engines connected with the condenser, which was designed for 1,000 I.H.P. or 20,000 lbs. of steam per hour; this sample contained one part of oil to a million of water. It was rather a difficult matter to separate the oil and the water completely out of the steam. At first he had made a mistake in not fully realising the high velocity of the exhaust steam and water rushing along the long straight length of exhaust pipe into the separator. The velocity was so great, that the arrangement which was good enough for the ordinary high-pressure steam separator was altogether inadequate for the exhaust separator. A sample of the condensed water was shown, which had been taken before the separator was altered, and it would be seen there was a considerable quantity of oil in it. It was then noticed as a curious thing that, when working with the condenser just condensing the steam at atmospheric pressure and not under a vacuum, the separator acted fairly well, the condensed water being pretty clear of oil at full load: so that evidently its action was affected by the velocity of the steam and water entering it. A sample was also shown of the condensed water taken under a light load of only about 100 I.H.P., and it was seen that there was practically no oil at all in it; it looked quite clear.

Mr. BRYAN DONKIN asked what was the proportion of oil caught in the separator, as compared with the total quantity of oil used in the engines.

Mr. BARLEY replied that it was about 98 per cent. of the total oil used in the engine cylinders, in addition to a small amount of lubricant drawn from the crank chambers of the enclosed engines; and the water and oil caught in the separator were together about

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8 per cent. of the total weight of feed-water supplied to the engines, the steam from the boilers being fairly dry but not superheated. Practically all the oil was caught in the separator; there was not more than one part of oil in a million of the condensed water taken from the condenser. There were many points however requiring careful attention in designing an arrangement of this kind. The oily water collected in the separator had to be got rid of. The condenser was some distance from the separator, and the remote ends of the eighteen parallel sections of condenser tubes were each about 200 feet run in series from the engines. There was consequently a higher pressure and temperature in the separator than at the remote end of the condenser whence the air suction-pipe was led off to the air pump. If therefore the bottom of the separator was connected by a pipe with the suction of the air pump to extract the water from the separator, the heat of this water would keep the air pump at a temperature and consequent pressure above that in the remote end of the condenser, and there would be no air suction at all from the condenser; the air would continually accumulate in the condenser. It was accordingly necessary for the water extracted from the separator to be cooled down by an auxiliary cooler before it was taken through the air pump. It was the only water taken through the air pump in this arrangement, and it was desirable to cool it as much as possible, because the cooler the air-pump suction-chamber was kept the better; for if this chamber was cool, it condensed the vapour out of the mixture of air and vapour drawn from the condenser. This rendered the air pump much more efficient, because its cylinders were filled at each stroke with air only, instead of with a mixture of air and vapour. Under these conditions a far smaller air pump than was generally used would suffice. The auxiliary cooler should be made like a small ordinary surface condenser, and through it the cold make-up for the circulating water drawn from the water main should be passed on its way to the circulating-water tanks overhead. It was most important to insert a U bend in the suction pipe between the separator and the air pump, and to make it lead down two feet or more below the bottom of the separator, and up again to the air pump, so as to form a water trap

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(Mr. C. J. Barley.)

for preventing vapour from being drawn from the separator, seeing that the pressure in the separator might at full load be one lb. per square inch, or more, above that in the air-pump suction-chamber.

The necessity of having good joints had been referred to in page 205. Even with the best joints however, if proper provision were not made for the expansion of the long exhaust, condensed-water, and air pipes, leading to and from the condenser and connected with each section thereof, the result would not be satisfactory. Great attention had been paid to this matter at Knightsbridge, with most satisfactory results. After the final water-test, the condenser was used for some months in the winter merely condensing steam at atmospheric pressure, and was necessarily subjected to a range of temperature between boiling and freezing. When the air pump and connections were finished, a test was made to try the joints. The air was pumped out of the condenser, with the engines shut off, and a vacuum was obtained within an inch of that of the barometer. That was owing not altogether to the tightness of the joints, but partly also to the excellence of the Edwards air pump. It was highly desirable, if possible, to have a large hot well, and a good ball-cock or other device to prevent the water level from being reduced by irregular feed below the level of the outlet of the barometric pipe leading from the condenser to the hot well, which would cause a sudden loss of vacuum. After a twelve months' trial of the condensing apparatus at Knightsbridge, he was able to say that the cast-iron corrugated tubes of the Ledward condenser were easy to clean thoroughly of scale on the outside, and showed no sign of deterioration; there was no trace of oil in the condenser. The working of the whole required no extra labour, and effected a considerable economy. Moreover when working under vacuum the pulsation in the exhaust pipes ceased, and one cause of vibration was thus eliminated.

In Plate 65 were plotted observations taken at the Knightsbridge station in a condenser test of 7½ hours' duration on 10th March 1899 from 4.30 p.m. to 12.0 midnight. The temperature of the atmosphere was 49° Fahr., and the wet-bulb thermometer 44°, and the dew point was 38·6°; the barometer was 29·9 inches, and there

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was a slight westerly wind. The quantity of water circulated was 30,000 gallons per hour, and the capacity of the circulating-water tanks was 22,000 gallons. The condenser contained 540 cast-iron corrugated Ledward tubes, 5 inches diameter inside the corrugations and 10 inches diameter over them outside; each tube was 5 feet long, containing 23 corrugations, and the metal was 3-8ths inch thick. The total evaporative surface exposed to the atmosphere was about 11,800 square feet. Every quarter of an hour during the test, observations were taken simultaneously of the weight of steam condensed per hour, of the temperature of the circulating water, and of the vacuum at three points:—namely at the air pump and remote ends of the condenser, plotted in curve A; at the condenser inlets, curve C; and at the engine-room exhaust-main, curve E. At the beginning of the test at 4.30 p.m. the weight of dry steam condensed was at the rate of 2,300 lbs. per hour. The load on the engines gradually increased up to a maximum of 26,000 lbs. of steam per hour at 7.0 p.m.; and then gradually decreased to 3,000 lbs. per hour at 12.0 midnight. Comparison should be made between the falling vacuum curves on the left of the maximum load, when the load was increasing, and the rising vacuum curves on the right, when the load was decreasing. On the increasing load, the condenser acted partly as an evaporative and partly as a surface condenser; whereas on the decreasing load, at and below 20,000 lbs. of steam condensed per hour, its cooling action was entirely evaporative. The condenser was designed for 20,000 lbs. of steam per hour; and comparing the vacuum obtained at this load in each case, it would be seen that the highest vacuum was 26·3 inches with surface and evaporative action in combination, the temperature of the circulating water being 84°. With evaporative action only, the highest vacuum was 21 inches, the circulating water being at 126°, and its temperature on the point of falling. Large storage water-tanks were a necessary safeguard in electric-lighting stations; and the above results showed they would lead to economy when condensing, by keeping up the vacuum over the peak of the load, thus reducing the size of condenser, the number of boilers under steam, and the coal bill. The large loss of vacuum between the remote ends

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(Mr. C. J. Barley.)

of the condenser sections, the condenser inlets, and the engines, as shown by the three vacuum curves A C E, was evidently due to the throttling of the vapour. The size of the 18-inch exhaust-main was limited by the space available; but the loss across the condenser itself could have been eliminated by coupling up each section with two tubes in series and fifteen in parallel, instead of with thirty tubes in series.

The Edwards air pump was a vertical three-throw pump, with cylinders 12 inches diameter and 12 inches stroke, and was driven direct by a Lundell six-pole series-wound 200-volt electric motor running at 100 to 150 revolutions per minute. The armature wound upon a sleeve was keyed direct upon the overhanging continuation of the pump crank-shaft, without any outer bearing. The magnets were bolted to brackets cast on the pump casing, and were adjusted to take part of the weight of the armature off the bearing of the pump crank-shaft. The power required to drive the air pump, with normal quantity of air being extracted, was about 5 brake horse-power, and did not vary appreciably with the vacuum so long as the pump was kept cool; and a maximum of 7½ B.H.P. for between 5 inches and 12 inches of vacuum, when pumping the air out of the condenser before starting the engines.

Mr. W. H. PATCHELL said that, when he tried the evaporative condenser which was erected at the Charing Cross and Strand Electricity Supply station, a great deal more oil was got out of the condenser than went into the engine cylinders. The explanation was that the engines, like those at Knightsbridge, were enclosed, and running in oil, and he could not say how much oil found its way from the crank chamber into the condenser.

For anyone having to construct an evaporative condenser the paper was particularly valuable, showing in many instances how not to do it, which was as important as how to do it. With the exception of the Ledward cast-iron condenser at the Knightsbridge station (page 191) and the cast-iron condenser experimented upon by Mr. Longridge (Table 2, page 200), there were practically no data furnished in the paper as to the performances of evaporative condensers; and this was the information which was really

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required at the present time. A condenser like that shown in Plate 53 had been ordered by his company to be put up in 1896, and it was not at work yet, having been through various changes of circumstance, somewhat like those encountered at Hastings by Mr. Andrews (page 218). The first trouble was with the condensing tubes, which were made with sliding joints and india-rubber rings at the top and at the bottom; the rings promptly failed. Then the makers who had it in hand tried making fast joints at the top by expanding the top ends of the tubes into the tube plate, and letting only the bottom ends slide. It seemed rather the wrong way to have the tubes hanging from the top, instead of standing on their base; but by fixing them in the tube plate at the top, and letting them slide at the bottom, the glands at the bottom were enabled to be drowned, so that if any little leakage occurred it was a leakage of water and not of air; and this advantage quite compensated for the tubes hanging instead of standing.

With regard to the advantage of an internal tube inside the condensing tube, as mentioned in page 186, he was sceptical. They had been inserted in his condenser, and from the absence of any effect upon the condensation he could not tell when they were in and when they were out. The cooling of steam in the condenser tubes he thought was generally looked upon as being rather like the cooling of hot gases passing through the tubes of a multitubular boiler; in the latter case the idea was that a central core of hot gases went straight through the tubes. But if the shrinkage of the steam against the condensing tubes was considered, it would be seen at once that—at the rate of condensation per square foot quoted by the author (page 196), namely 8 lbs. of steam per hour, and taking 120 cubic feet as the volume of 1 lb. of steam exhausted at about 12 lbs. per square inch below atmosphere—there was a motion of the steam towards the walls of the tubes at a velocity amounting to nearly one thousand feet an hour, quite apart from the motion of the steam in passing through the tubes. In contrast with this sort of compound motion of the steam, due to condensation against the tube surface, the hot gases passing along a boiler plate or through flue tubes underwent no shrinkage equivalent to that arising from condensation, to draw fresh hot gases into contact with the metal surface.

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(Mr. W. H. Patchell.)

The distribution of the cooling water over the condensing tubes was a trouble, especially with vertical tubes; and he agreed with Mr. Donkin (page 208) that really the dirt was the worst trouble. He had not tried a chain of saucers on each tube, as shown in Fig. 3, Plate 41, but only a single saucer on each, as in Fig. 54, Plate 54; and possibly because a dust destructor was in the neighbourhood, they had promptly filled up with dirt; if not with dirt, they promptly filled up with scale out of the water. A pretty liberal clearance had been allowed for the water to get through; yet he had come to the conclusion that this was the best way of keeping the water off the tubes, for the saucers speedily became clogged up with dirt or scale, and then the water, instead of getting some sort of course down the outside of the tube, practically fell clear of it altogether. The best way he thought was to place water-deflecting boards between the tubes; then if the water fell off the tubes, it was caught on the boards and fell back again upon the tubes a little lower down. The wire netting, Fig. 2, Plate 41, was just as bad as the saucers, if not worse; the scale formed on the tube or netting, and instead of falling clear off the tube it fell on the netting, and was re-cemented there with freshly formed scale, so that a thicker scale was possible with the netting than without it. It was better he thought to supply a much larger quantity of cooling water over the tubes.

The arrangement of the condenser shown in Plate 58, which had been tested by Mr. Longridge (page 213), was the same he thought as one he had seen in Dundee some eight or nine years ago. The name however of the firm by whom it was made had been changed from Messrs. Cooper and Grieg to Messrs. Whyte and Cooper. At that time condensers of this kind were not at all uncommon in Dundee. At the electrical station one had been put up on the roof, in regard to which he had endeavoured to ascertain the working results, but had not succeeded in doing so.

Mention had been made by Mr. Andrews (page 219) of the benefit derived from what might be called the water leg, or as Mr. Barley had called it (page 226) the barometric pipe, from the condenser down to the hot well. In his own condenser he had done his best to

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get the makers to take advantage of the 30 to 35 feet depth from the bottom box of the condenser down to the hot well; but he had not succeeded in getting them to do so. They had insisted on drawing off the air from the top of the condenser and the water from the bottom through the same pipe, which delivered its contents to the air pump.

The condensers described in the paper practically completed the list of evaporative condensers, if the Cochrane cylindrical condenser mentioned by Mr. Longridge (page 211) were added thereto. The only place where he had seen that condenser working was Messrs. Siemens' works at Woolwich. Some information had also been given in a short paper which had been prepared for the Chicago meeting of the American Society of Mechanical Engineers in 1893 (Transactions, vol. 14, page 690) by the late Mr. James H. Fitts, professor of mechanics and physics in the Virginia Agricultural and Mechanical College of Blacksburg, Virginia, who had there made a condenser with horizontal brass tubes wholly submerged in shallow troughs of cooling water; the plan was probably that of which Mr. Donkin had mentioned (page 210) that he had read. There were altogether 210 tubes, each No. 20 B.W.G. or 0·036 inch thick, $\frac{3}{4}$ inch external diameter, and 4 ft. 9$\frac{1}{2}$ ins. long; and there were twenty-seven troughs, arranged one above another, with 8 tubes each in 21 of the troughs and 7 each in the remaining 6 troughs; all the tubes in each trough were on the same level, and opened at each end into a vertical steam-chamber. One chamber was divided at the middle of its height by a transverse diaphragm, so that the exhaust steam entering at the top traversed the tubes in the upper half of the condenser and returned through those in the lower half, the condensed water being drawn off from the bottom. There had been such trouble however in getting the exhaust pipe tight that Mr. Fitts had been obliged to give up all idea of using the condenser on his college engine before the Chicago meeting; and the figures given in his paper related to steam generated in a boiler close by, at 60 to 70 lbs. pressure per square inch, and condensed direct in the condenser. The general conclusion arrived at from a number of trials of several hours'

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(Mr. W. H. Patchell.)

duration was that the cooling water required was practically equal in weight to the steam condensed. Mr. Fitts had further plotted two interesting curves, showing the effect of the temperature of the cooling water upon the rate of evaporation when working the condenser with an exhausting fan, and also without the fan, that is, in still air. In both cases the barometer averaged 28 inches of mercury, and the vacuum 16½ inches. With the cooling water at a temperature of 60° F., the evaporation in still air was about 0·1 lb. per square foot per hour; and on heating the water up to 180°, it evaporated at the rate of 2·75 lbs. per square foot per hour. With the exhausting fan drawing air horizontally across the water troughs at a velocity of 2,300 feet a minute, the evaporation was 0·8 lb. at 93°, and 9·5 lbs. at 160°; without the fan it was 1·45 lbs. at 160°. Here therefore it could not be said that the fan was of but little use (page 203). The first mention he had met with of a proposal to attach a fan to an air surface condenser was in "Engineering," vol. 7, 1869, pages 185 and 187–8, which was of some interest because several years later the use of a fan for this purpose had been claimed as a novelty in England. Also in vol. 9, 1870, page 383, there was a description of an evaporative surface condenser designed by M. Jean François Cail of Paris, which was well worth reading.

The PRESIDENT was sure the Members would be interested to hear from Professor Goss, of Purdue University, Lafayette, Indiana, U.S.A., who was on a visit to this country, anything he could tell them in regard to American experience with evaporative condensers.

Professor W. F. M. Goss said that, so far as he knew, the individual evaporative condenser which had been referred to by Mr. Patchell (page 231), as having formed the subject of a paper presented by Mr. Fitts at the Chicago meeting of the American Society of Mechanical Engineers, was the only one that had been worked at all in America. That, as he remembered, was a small condenser, constructed entirely for experimental purposes; and he did not know of any evaporative condenser having been used [illegible]ly in America. Cooling towers however were used in

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connection with surface condensers; but on the whole the condenser had not received the attention in America that it had evidently received in England. Many large works had been running with the exhaust going into the atmosphere, in almost every town and city where steam engines were used. With regard to the cooling towers, the practice in America had settled down to the use of unglazed tiles inside the tower, instead of the slanting wooden slabs or shelves which had been described by Mr. Spencer (page 222) and were shown in Fig. 83. Cylindrical tiles of 4 to 6 inches diameter were used, in lengths of about 1 foot, and were placed standing on end in courses, and breaking joint in the successive courses. It would be seen that water which was sprayed from the top of such a tower was well divided, and was kept divided throughout its course to the bottom of the tower. Water coolers constructed of horizontal tubes were also used in America, but were not employed as condensers. They were used for cooling the jacket water of gas engines, and also of course in connection with refrigerating machinery.

The PRESIDENT had hoped the meeting would have the pleasure of the presence of Sir Frederick Bramwell, who had long ago had some experience in this mode of condensing. Unfortunately he was not able to be present; but Mr. Williams would offer some remarks on his behalf.

Mr. HAL WILLIAMS said the essence of the success of the evaporative condenser appeared to lie in the distribution of the water over the condensing tubes. Several arrangements of distributing troughs were illustrated in the paper, but that shown in Figs. 11 and 12, Plate 42, was the only one which seemed to him to approach in any way to what was found by experience to be best: namely a top slotted pipe placed over the top of the condenser tubes, and supplied with water from a tank placed in the middle of its length. It was first introduced into this country he believed by Messrs. L. Sterne and Co. of Glasgow, in connection with their ammonia condensers; and it had been used both for that purpose, and also in a slightly modified form for other condensers. In Figs. 87 and 88, Plate 66,

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(Mr. Hal Williams.)

were shown an elevation and plan, and in Fig. 89, Plate 67, a side elevation of the ammonia and steam condensing arrangements in connection with a liquor-cooling plant, which had been put up by Messrs. Bramwell and Harris at Messrs. Meux's brewery in London. The ammonia condenser was placed on the top of a staging on the roof of the engine house, and the cooling water was pumped into a tank in the middle of the length of the condenser, and flowed both ways through the slotted pipes, running down over the condenser tubes into a tank beneath them. Thence it was delivered upon the top of the steam condenser, situated underneath the ammonia condenser; and after flowing down over the steam-condensing tubes it was cooled artificially in readiness for being used over again upon the ammonia condenser. It would be seen that the steam condensers were placed not directly under the ammonia condensers, but diagonally; they were so arranged in order that a duplicate of either condenser might be put in at a future time, if desired; and also in order that the steam arising from the steam condenser should not impinge directly upon the tubes of the ammonia condenser. One of the great drawbacks to the more extensive introduction of evaporative condensers was the large amount of steam evaporated from the outside of the tubes, which produced what he believed Sir Frederick Bramwell had once called a "washing day" effect. The figures quoted by Mr. Patchell (page 232) from the tests of an experimental evaporative condenser at the Agricultural College in Virginia showed rather conclusively the value of taking the utmost advantage of the latent heat by evaporating the water from the outside of the condenser. It would appear that a better result might be obtained by passing a smaller quantity of water over the tubes and evaporating nearly the whole of it, than by pouring over them a larger quantity of which so much less was evaporated. The difference of opinion that existed on this point was rather clearly shown by the fact that the Fraser condenser used he believed from 40 to 50 lbs. of cooling water per lb. of steam condensed, the Theisen from 20 to 25 lbs., and the Royle condenser from 5 to 10 lbs. only.

lan of economising the condensing water had been used in aces by Messrs. Bramwell and Harris, and had always been

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found to work successfully. But frequently the condensing water was found to be exceedingly hard and dirty; and this seemed to be one of the greatest troubles with evaporative condensers. The carbonate of lime coated the outside of the condensing tubes, and deteriorated their conductivity considerably. The simplest way of getting rid of it, as suggested in the paper (page 204), was found to be by turning off the cooling water and allowing the exhaust steam to expand the tubes; the scale could then easily be removed by means of a wire brush. One of the most important points in designing an evaporative condenser was to keep the tubes a sufficient distance apart, so that they could easily be got at everywhere for cleaning, and could readily be removed and replaced.

The diagram, Fig. 90, Plate 67, was rather interesting as representing he believed absolutely the first evaporative condenser that was ever introduced. It had been designed by Pontifex in 1836, and was used in connection with an apparatus for concentrating sugar juice. The vacuum pan V was heated in the ordinary way by a steam worm; and the steam rising from the partly concentrated liquor therein passed through the tubes of the evaporative condenser E, where it was condensed by the weaker juice to be concentrated, which flowed out from the tank T, and was distributed by the trough D over the tubes of the condenser, and trickled down over them into the receiver R, whence it flowed into the cisterns C. From these it was drawn up by the vacuum into the measuring vessel M, and thence delivered into the vacuum pan V. The condensed steam from the inside of the evaporative condenser flowed away from the bottom at A to the air pump.

Mr. WILLIAM BROWN said the Cochrane cylindrical condenser referred to by Mr. Longridge (page 211) and Mr. Patchell (page 231) had been in use at Messrs. Siemens' Telegraph Works at Woolwich for twenty-six years. It consisted of a number of vertical cast-iron double cylinders, one inside the other, as shown in Figs. 91 to 93, Plate 68, each 12 feet high; the outer was 44½ inches diameter outside, and the inner 40 inches diameter inside; between them was an annular space of about 7-8ths of an inch, into which the exh-

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(Mr. W. Brown.)

steam was led at the top, the condensed water being drawn off from the bottom. The cooling water was allowed to run down the outside of the outer cylinder and the inside of the inner, from an annular trough at the top into a similar trough at bottom. One square foot of surface sufficed to condense about 1½ lb. of steam per hour. The first portion of the condenser was erected in 1873, and consisted of eight double cylinders; by additions made in 1880 and again in 1881 it had been extended to its present size, consisting of twenty-seven double cylinders. These were capable of dealing with 550 I.H.P., or of condensing 11,000 lbs. of steam per hour and producing a vacuum of 28 inches of mercury, when the cooling water was circulated at the rate of 24,000 gallons per hour over the whole condenser. The cooling water, obtained from the Kent Water Works, was hard, containing as much as 30 grains of solid matter per gallon; it produced a heavy deposit on the condensing cylinders at the rate of about 3-8ths inch thickness per annum. In order to remove the deposit more easily, a certain amount of boiler composition was added to the cooling water, and the cylinders were periodically scaled all over. The floor space occupied per I.H.P. was 2 square feet; and the weight of the condenser was 16 cwts. per I.H.P., including the connecting pipes. Although perhaps seeming somewhat out of date, the condenser had an important advantage in the ease with which it could be cleaned: nothing could be more simple than the cleaning, because a man could get all round the whole of the cylinders both outside and inside; and the outside surfaces could be cleaned while the condenser was in use. At the present time all the cylinders were practically as good as the day they were erected; and the cost of maintenance had been trifling, owing to the small amount of repairs necessary. A third advantage was the small consumption of cooling water, the evaporation amounting to not more than two-thirds of the weight of the steam condensed. There were two serious drawbacks. One was the extent of floor space occupied, which amounted to as much as 40 square feet for each double cylinder. The other was the weight, which was so great in consequence of the size of the cast-iron cylinders, and was further augmented by the thickness of the accumulation of scale

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upon them. Some of them had been taken down and thoroughly cleaned in 1894; and it was then found that, although they were practically as efficient at that time as when first put up, scale of such thickness had formed in places as to show that if no scaling were done on them an allowance would have to be made for increase of weight amounting to as much as one ton for each double cylinder in the whole condenser. Consequently the structure to carry them had to be carefully considered. In view of the facility for cleaning and repairing he thought there was nothing better, where there was plenty of space. This condenser stood in about the same relation to the more modern evaporative condensers described in the paper as did the old egg-ended boiler to the modern water-tube boiler, in regard to repairs and cleaning.

Mr. OLDHAM quite agreed that one of the principal difficulties which had to be dealt with in evaporative condensers was the dirt on the outside of the tubes. Of vertical condensers with brass tubes sliding through the top water-tank he did not know one that had been working satisfactorily; the narrow annular space through which the water flowed down over the tube often got filled with dirt, and then the tube was left dry, without any cooling water flowing over it. Moreover the pitch of the tubes was often so small that nothing could be got in between them to scrape the scale off: although the scale did not stick to the brass tubes as it did to the cast-iron. The horizontal condenser shown in Plate 47, which might be made with wrought-iron or cast-iron tubes, could be got all round for removing the scale; and it must be cleaned periodically, or efficient results were not obtained. In that condenser the spaces were more than 1 foot clear, so that about once a month or so, with a wire brush for a scraper, the dirt could be removed from the tubes. It was found that in the cast-iron condensers the scale stuck to the tubes much more than it did on wrought-iron tubes; from the latter it could easily be removed by tapping the tubes, when it broke away quickly; but from cast-iron tubes it did not.

Cylindrical tubes were considered by Mr. Donkin (page 209) to be better than tubes of complicated section; and perhaps there was an

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(Mr. Oldham.)

advantage in having cylindrical tubes, because in tubes with grooves or depressions the latter often got filled with scale and dirt, although if ample room were allowed the Kynoch tube of heart section, shown in Figs. 81 and 82, Plate 63, could be easily cleaned. If the ends of horizontal iron tubes were expanded into the tube-plates, they answered as well as flanged joints, and in some cases better.

The power required for driving a fan in connection with a condenser (page 210) was about 2 to 3 per cent. of the total engine power, as far as his own experience went. With regard to the low value assigned to fans (page 203), it was true that in Mr. Row's experiments (Table 3, page 201) the condensation was increased 50 per cent. by the air current; and in the experiments quoted by Mr. Patchell (page 232) the value of the fan appeared to be even greater. But these results were experimental; and although fans designed specially for experimental purposes might give such favourable results, yet in practice, when fans were applied in the manner shown in the five examples, Figs. 74 to 78, Plate 61, the value of the air current was practically nullified, and all that the fans were doing was simply wafting a gentle movement of air through the condenser. Sometimes the result was not more than 1 per cent. increase of condensation; and Mr. Andrews had found (page 220) that when the fan was running the result obtained was no better than when the fan was idle. In an experimental condenser containing a great nest of tubes he could imagine that a fan might increase the condensation as much as 50 per cent.; and the condenser mentioned by Mr. Patchell (page 231) as having been tried in America had been stated by Professor Goss (page 232) to be entirely an experimental apparatus.

The remarks made about getting the oil out of the exhaust steam (pages 216 and 223) were highly important. It was well known what great mischief oil did when it got into a boiler.

The plan of putting wet blankets over the condenser tubes, about which Mr. Longridge had enquired (page 217), had been tried in a Theisen condenser. A special fabric was wrapped round each of the tubes, so as to keep the cooling water close against them; t he had not heard any particulars as to the results. It had also n proposed to put a special fabric—either wire-netting or felt or

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rough canvas—for a wrapping round the Kynoch heart-shaped tube shown in Fig. 82, Plate 63; but the very alternatives mentioned in the proposal seemed to him to betray ignorance of the principle of evaporative condensers.

In the first brass-tube evaporative condensers which had been erected, the extent of condensing surface provided had been 1 square foot per 10 lbs. of steam condensed per hour, or 6 square feet per lb. of steam condensed per minute, as quoted by Mr. Longridge (page 212); but how that proportion had been arrived at he could not understand. That was about the surface provided in marine surface-condensers, and he had not been able to find out how it ever came to be adopted for evaporative condensers. All the makers of brass-tube evaporative condensers seemed to have been led away by that proportion, and all appeared to have adopted it; Mr. Theisen he thought was responsible for its adoption in the first instance. In experiments on the Continent marvellous results were said to have been obtained from evaporative condensers, which engineers in this country had not been able to investigate, owing to the expense and time involved. Those who had accepted as the standard a condensation of 10 lbs. of steam per hour per square foot of surface for vertical brass-tube condensers with fans had been led into serious difficulties. That extent of surface would be large enough if the fan doubled the condensing efficiency; but it did not. A number of electrical engineers had had to incur the expense of making experiments for themselves on this matter with this kind of condenser, and other engineers had to thank them for it. There was no doubt that a horizontal evaporative condenser with wrought-iron tubes, having about 1 square foot per 3 lbs. of steam to be condensed per hour, would do its work efficiently, without requiring any fan at all. As long as there was a good quantity of cooling water, say 10 to 20 times the weight of the steam condensed, he thought such a condenser would answer all requirements.

A large amount of steam was given off from the top of an evaporative condenser; but that was certainly what occurred wherever steam engines were at work non-condensing. If it was required to co

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(Mr. Oldham.)

the water for a jet condenser in a cooling tower, a large volume of steam came out of the top of the tower, and was blown about; but this was not so much of a nuisance as the steam coming direct from the exhaust pipe of a non-condensing engine, because the steam from the tower was divided much more finely, and was sooner condensed round about. A cooling tower seemed to him not to be required with an evaporative condenser, because if it was put up there were two appliances for doing the work of one. In Glasgow there had recently been erected a cooling tower 12 feet diameter and 31 feet high for cooling the water for a surface condenser for condensing 10,000 lbs. of steam per hour, or 500 H.P. In addition there were the surface condenser itself and air pump, the circulating pump for the condenser, and also pumps for circulating the water in the tower. The ground space occupied by the cooling tower alone was 1 square foot per 5 H.P.; and as some evaporative condensers took but little more space than this, it would appear that not only would a large amount of room be taken by the cooling tower, but there would be two separate sets of appliances for doing what an evaporative condenser could do at once by itself. In some of the cooling towers which were constructed with galvanised netting inside, the netting rotted away quickly. When it was possible to have condensers which did the work without the aid of a cooling tower, he did not see that the cooling tower was any advantage. [See also page 252.]

The PRESIDENT trusted the discussion upon the present paper on evaporative condensers would lead to another paper being written on the interesting subject of water cooling, in order that it might be realised more fully what could be achieved in practice by the latter plan in comparison with the former.

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Mr. HORACE BOOT, Borough Electrical Engineer, Tunbridge Wells, wrote that he did not agree with the statement in page 185 that the amount of condensing water used with an evaporative condenser might be from 25 to 30 per cent. less than the amount of feed-water used when the engines were non-condensing; the reduction he considered should be from 10 to 15 per cent. only. The works at Tunbridge Wells were one of the first to adopt the Wright evaporative condenser; and it might be interesting therefore to give briefly the results of a test conducted in May 1898. The tubes are of brass, sixty in number, of No. 19 wire-gauge or 0·04 inch thickness, and 2½ inches diameter. The test was conducted for six hours under a steady load giving 10,680 lbs. of steam per hour to be condensed. The vacuum maintained during this time was 21·45 inches of mercury, the guarantee being 24 inches. The condenser was new and clean; it had been previously tried, and had proved a failure, but by subsequent alterations had been brought up to the above state of efficiency. The temperature of the cooling water in the sump was 130° F.; but in order to get good results the writer considers it should not exceed 120°. In another test, made under nearly the same atmospheric conditions after the condenser had been working six months continuously, it was found that it had deteriorated, and that in order to maintain the same vacuum it was capable of condensing only some 7,000 lbs. of steam per hour, although the tubes were not particularly dirty. The rapid deterioration however is a great drawback to evaporative condensers.

The principal difficulty seems to be to get the cooling water to distribute itself evenly all over the tubes. Several different plans were tried, and he finally came back to wire netting, Fig. 2, Plate 41. The method of cleaning suggested in page 188, by moving the netting up and down, is quite impracticable. A neat method is by passing steam through the tubes without water, thereby expanding them sufficiently to cause the scale to chip off inside and outside; and on then brushing the tubes, all the scale falls to the bottom.

Wrapping a blanket round the tubes, which Mr. Longridge asked about (page 217), was tried by the writer; but the only result was that bits of the blanket had to be picked out of the valves of th circulating pump.

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(Mr. Horace Boot.)

Sufficient attention he thinks is not given to the power absorbed by air pumps and circulating pumps, and to the capital outlay involved in comparison with the saving effected when condensing. If more consideration were bestowed upon these points, a far greater saving could be effected by condensing than is at present realised. With many evaporative condensers it seems doubtful whether any actual saving whatever is effected, owing mainly to the inefficiency of the pumps and to the power expended in circulating the cooling water.

Mr. DONALD ENOCK wrote that the author had mentioned (page 240) that some cooling towers were constructed with galvanized wire mats, over which the water was distributed, and that these mats rotted away quickly. There is only one kind of tower at the present time, the writer believes, which has this plan in use, namely the Barnard-Wheeler tower; and one set of wire mats has been in continuous use for five years in one of these towers in connection with a tramway. In this instance the water is slightly brackish, and there is no sign of either wear or rotting from use or exposure. As far as he knows there are no instances of the mats having deteriorated in any way. They are of steel wire and small mesh, galvanized after being woven; and each intersection is covered with a solid mass of spelter, thus protecting the parts most open to corrosion.

The remark of Mr. Andrews, that the use of a fan made practically no difference in the efficiency of his evaporative condenser (page 220), may well apply to evaporative condensers in general, for the reason that it is practically impossible to make a fan large enough to distribute the air current effectively over all parts of the condenser. When in an exposed position, the evaporative condenser will do much better with natural draught, as opposed to forced or induced draught, because the casing and chimney required for the latter are too cumbersome for practical use, excepting in the Wright and other similar condensers, which being vertical are more adapted for the employment of a fan; but if cased in for a fan they are useless for natural draught.

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There always remains the fact however that on a damp muggy day, when no air is moving, an evaporative condenser cannot be expected to work efficiently, and reminds others besides Sir Frederick Bramwell of a general washing-day (page 234). An instance is furnished by the apparatus on the roof of the Brighton central electric station; alongside is a Barnard tower doing excellent work, which is itself a standing proof of the advantages of a surface condenser and water-cooling tower combined, in comparison with an evaporative condenser. From an examination of the two plans where in use in this country, the writer is satisfied that, in regard to weight and ground space taken together, and economy and ease of working, an evaporative condenser is not to be compared with a combined surface-condenser and water-cooling tower.

The special points to notice in water-cooling towers are that the water should be divided into as thin sheets as possible, and be exposed on each side of the sheet to a large quantity of air at a low speed. Those towers in which the free passage of air is impeded by overlapping tiles or wooden shingles can never give complete satisfaction, because of the obstruction thus offered to the air.

In the discussion upon a paper read to the Cleveland Institution of Engineers by Mr. Horace W. Jarvis of Middlesbrough, the following particulars were given by Mr. Marston of Middlesbrough (Proceedings 1899, page 91), respecting the ground space occupied per I.H.P. by different methods of water cooling:—deep pond, 39 square feet; pond with sills or terraces like Whitwell's, 13; Körting spray cooler, 7; Klein open cooler, 2·3 square feet. The cost per I.H.P. was:—deep pond, £3 15*s.*; Whitwell pond, £2; Körting sprayer, 17*s.* 6*d.*; Klein open cooler, 13*s.* 6*d.*

The writer is informed by Mr. Reavell, of the Blake Knowles and Barnard-Wheeler tower cooler, that a water-cooling tower of any capacity required can be erected at the rate of 2½ cwts. per square foot of its base, including supply pump and water; and that at the present time a cooling tower is in use, mounted on a roof two storeys high, and having a cooling capacity of 8 horse-power per square foot of base, while another is being erected with a cooling capacity of 16 horse-power per square foot of base.

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Mr. ROBERT HAMMOND wrote that electrical engineers had frequently to erect generating works on sites where ample water for condensing was not available; and at the present time he was himself concerned with designs for three places where the problem of condensing at a distance from either river or canal had to be dealt with. The impression he had derived from the paper and discussion was that the evaporative condenser must be avoided, as sufficient reliance could not yet be placed upon it. There was one point not dealt with in the paper, upon which he should like to have some information: namely, what was the actual monetary saving realised by the use of an evaporative condenser. Naturally the main object in condensing the steam was to effect a saving in coal; and he should be glad to know whether sufficient data had been obtained for stating, on the one hand, the value of coal saved during twelve months, presuming that the boilers supplying the main engine were also supplying the air and circulating pumps; and on the other hand, the annual interest on capital expenditure, the annual sum for deprociation, and the annual amount of wages and repairs.

Mr. H. H. RHODES JAMES wrote that, although the paper gives much information regarding the construction of evaporative condensers, it contains little as to their performance, which latter appears in some instances to be hardly satisfactory. It would be of interest to have some data as to the vacuum obtained with a well designed condenser under different conditions of atmosphere and load. Probably a vacuum of about 20 inches of mercury would be considered highly satisfactory; and it is doubtful whether a higher vacuum would be maintained for any length of time, unless under a light load.

With regard to the statement in page 197, that a 16 H.P. engine drives the circulating pump and fans for condensers dealing with 3,000 H.P., it seems questionable whether the power required for driving the fans would not greatly exceed 2 per cent. of the total engine power (page 204), at all events in comparatively small installations

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The average cost of the evaporative condenser (page 206) appears to be considerably over 20*s.* per I.H.P. for small sizes; and it may perhaps be of interest to give some figures of the estimated cost of a 100 H.P. condenser with horizontal cast-iron corrugated tubes. The condenser alone would cost £175 for this power; belt-driven air and circulating pumps would increase the amount to £270; adding to this the cost of a small engine or motor, the connecting pipes, cooling-water tank, girders for carrying the condenser, and the erection of the whole, the total might be put at from £350 to £400, exclusive of extra outlay on the special design of roof. The space required for such a condenser would be about 18 feet by 13 feet or 234 square feet, against 90 square feet given in page 192 for this amount of power. The vacuum was expected by the makers to be from 22 to 24 inches of mercury. In framing estimates for various kinds of these condensers it would therefore appear desirable to allow at least £3 per H.P., including therein the cost of pumps, connecting pipes, and erection. For larger condensers it is doubtful whether this cost could be reduced, owing to the increased weight both of the condenser itself and of the pipe work. The practice of stating the cost of the condenser alone by itself appears likely to lead to erroneous ideas of the commercial value of the whole.

Mr. T. R. MURRAY wrote that most designers of evaporative condensers have adhered to some variety of the pipe form, which however he considers is not by any means the best adapted to meet the requirements. The chief objects to be attained in an evaporative condenser are the following:—firstly, to bring the steam into contact with the cooling surface as completely as possible; secondly, to abstract heat from the cooling surface by evaporating from its external surface a certain proportion of a thin film of constantly circulating water; thirdly, to keep up a constant and steady rate of evaporation; fourthly, to ensure that all power expended is thoroughly utilised; and lastly, to arrange all the parts so as to be readily accessible for examination and cleaning. Finding how defective in some or all of these respects are the various kinds of condensers in use, he some time ago devised and constructed on

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(Mr. T. R. Murray.)

different lines an experimental condenser, which gave remarkably good results. Instead of tubes, flat cells of thin corrugated brass sheeting are used, as shown in Figs. 94 and 95, Plate 68; the condensation takes place in their narrow internal spaces, and the cooling water flows in a thin film over their external surfaces. The steam is thus brought into intimate contact with the cooling surface, and there is no core of uncondensed steam, as there is believed to be so frequently in tubes. Special brass stay-strips are arranged inside the cells, to prevent them from collapsing; and a safety valve is placed on the exhaust inlet pipe, to provide against internal pressure; for the latter purpose also distance pieces are arranged between the cells. The flat cells are placed upright and parallel to one another inside a casing, with a narrow space between each; and through these narrow spaces passes a constant upward current of air from a fan, meeting and thoroughly intermingling with the descending water, thus ensuring that every particle of air and water does its proper work. This is an important matter; and much of the failure to appreciate the use of fans for evaporative condensing is due to their being generally so arranged that a large percentage of their work is wasted in circulating air which never comes into contact with the water at all, as exemplified in the condenser referred to by Mr. Andrews (page 220), where the fan was so inefficient that it made no difference whether it was running or not. The results obtained with the experimental condenser of this construction are given in Table 5: the steam supply was taken from the exhaust of a single-cylinder slide-valve engine; the area of the condensing surface was 114 square feet; the weight of water circulated was ten times the weight of steam condensed; the make-up water was taken from the main; the temperature readings were taken every ten minutes; and the Blackman air propeller of 24 inches diameter ran at 800 revolutions per minute. Provision was not made in these experiments for obtaining a vacuum, because this would of course be exactly the same as would be obtained from a surface-condenser delivering condensed steam at the same temperatures.

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TABLE 5.--*Murray Evaporative Condenser, Figs.* 94 *and* 95, *Plate* 68.

Date of experiment . . 1898	March	4	10	14	23	24
Duration of experiment . .	hours	3½	8	3½	2	4½
Temperature of condensed Steam leaving condenser . .	Fahr.	147°	122°	173°	136°	122°
Temperature of circulating Water entering condenser . .	Fahr.	119°	125°	125°	—	—
Temperature of make-up Water .	Fahr.	40°	40°	40°	41°	41°
Temperature of Air entering fan .	Fahr.	50°	55°	47°	58°	55°
Temperature of Vapour escaping from condenser . . .	Fahr.	146°	131°	161°	126°	118°
Weight of Steam condensed per hour	lbs.	1,576	1,080	2,073	1,336	1,032
Weight of make-up Water added per hour	lbs.	1,275	794	1,575	1,080	771

A condenser on this plan for 250 H.P. is now being made by the Mirrlees Watson and Yaryan Co., Glasgow, with full arrangements for completely testing it, and with separate electric motors for driving the fan, the air pump, and the circulating pump, so that the power consumed by each may be accurately ascertained. The expansion and contraction of the corrugated sheets prevent the formation of scale; and any condensing section can be readily removed and opened for cleaning. Owing to the fact that no space is wasted, the room occupied by the condenser is reduced to a minimum.

Mr. WILLIAM SCHÖNHEYDER wrote that an early pioneer in evaporative condensers was the late Mr. E. A. Cowper, who continually urged their great advantage; he believes it was owing to his advocacy that Messrs. Siemens Brothers of Woolwich erected twenty-six years ago the Cochrane condensers so highly spoken of by Mr. William Brown (page 235). Eight similar condensers were previously fixed in 1870, also under Mr. Cowper's directions, at Messrs. Anthony Gibb's works near the Victoria Docks. An evaporative condenser with horizontal tubes was also supplied by him at Messrs. De la Rue's works in Finsbury; and no doubt he erected many others (Proceedings 1862, page 119). But in spite of his perseverance, it is only in recent years that steam users have come to adopt them more generally. In 1868 the writer remembers seeing an evaporative condenser with horizontal tubes at the saw

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(Mr. William Schönheyder.)

mills of Messrs. Hudson and Carr near Vauxhall Bridge, which even then was far from being new.

In Fig. 46, Plate 52, and also in Plates 50 and 53, is shown a cooler for reducing the temperature of the air before it reaches the air pump, evidently with the object of improving the vacuum; but beyond a slight shrinkage in the volume of the air, whereby the air pump would be rendered a little more effective, he fails to see any advantage in the arrangement, for it is clear a vacuum cannot thereby be obtained better than that due to the general temperature of the body of vapour in the condenser, and it will always be somewhat worse. Can any trustworthy data be furnished to prove the benefit of such a cooler for the air only?

It would also be interesting and useful to have records of experiments as to the benefits derived from the internal spiral distributors, Fig. 15, Plate 42, which are said to have been devised by Messrs. John Fraser and Son (page 186). More than thirty years ago he made several experiments in this direction, but failed to find any advantage from their use.

In the Kensington and Knightsbridge condenser, Figs. 35 and 36, Plate 46, the branch pipes from the main exhaust are shown rising up to the top of the condenser. This he considers cannot be good practice, as it necessitates a separate drain from the main exhaust, which should itself be at the highest level, so as to drain into the condenser tubes. It is also incorrect in his opinion to allow the air-pump suction to rise after leaving the lower part of the condenser; as air is heavier than vapour of water at the same pressure and temperature, it should always be given a continuous falling gradient to the air pump. The troubles met with by Mr. Andrews at Hastings (page 218) he fears may have arisen partly from neglect of this fact. The practice of providing a drain pipe for the condensed steam, separate from that conveying the air, seems to present no advantage, because the volume of condensed steam is so small compared with the volume of air to be pumped, that the separation of the water will not materially reduce the pump capacity required for pumping out the air; and moreover the water in the

helps to seal the valves and bucket, and thus prevents loss by

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leakages in the air pump. For the same reasons it appears to be a mistake to lead the air-pump suction from the top of the condenser, as shown in Figs. 44 and 45, Plate 51.

An effective way of testing these condensers is to pump air into them, and to brush them over outside with soap and water; bubbles which can be easily observed will then appear wherever even the smallest leakage exists. As however it is almost impossible to prevent leakages from occurring in course of time in long lengths of pipes alternately heated and cooled, it is well not to be sparing in the capacity of the air pump, which in the writer's opinion should be larger than is generally provided for the ordinary surface condenser.

Mr. WILLIAM GEORGE WALKER wrote that the tendency referred to in page 186, for a central core of uncondensed steam to pass through the condenser tubes, is due to insufficient internal condensing surface; for steam, like air, requires more cooling surface than water. In experiments with tubes of the Serve pattern, having internal longitudinal vanes or ribs, he found about 25 per cent. more steam per foot run could be condensed than in plain tubes of the same diameter. The best results were obtained with vertical tubes, having their internal surface quite smooth, so that the condensed steam deposited thereon could easily drain off; the presence of a film of condensed steam on the internal surface appears to retard the transfer of heat. Provided economy of space and weight is no object, he thinks it possible to construct an air condenser pure and simple, without the aid of any evaporation of water. In experiments on this point about 2 lbs. of steam were condensed per square foot of surface per hour, with air blown over the surface at a velocity of 1,000 feet per minute: so that about 10 square feet of surface would be required per I.H.P., or about ten times the surface of an ordinary surface condenser. About 2,400 cubic feet of air are required to condense 1 lb. of steam. Therefore 100 H.P. would require about 1,000 square feet of surface and about 80,000 cubic feet of air per minute.

The success of either an evaporative or an air condenser will largely depend upon the proper arrangement of the fan; and in six

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(Mr. W. G. Walker.)

of the eight diagrams in Plate 61 the fans are shown forcing or propelling the air into the condenser. Better results are obtained in the writer's experience by suction of the air, so that it is drawn in from all sides through the condenser at a slow velocity to the fan, where it is discharged in a cylindrical column, which should not be baffled or blocked in any manner, but should have a free escape; whereas on the feeding or suction side the air current entering the fan can be baffled to a considerable extent without reducing the efficiency of the fan, providing the air space between the condenser tubes is not reduced too much. An exhausting fan 5 feet diameter, discharging 40,000 cubic feet of air per minute with practically a free inlet and outlet, required 6 H.P. to drive it; for 50,000 cubic feet it required 12 H.P., and for 60,000 cubic feet 22 H.P. When the air was baffled by a resistance equivalent to $\frac{1}{4}$ inch of water gauge beyond what it would encounter with free discharge, the fan required 12 H.P. in order to discharge 40,000 cubic feet per minute; and when the baffling resistance was equivalent to 1 inch of water gauge, it required about 24 H.P. in order to produce the same discharge.

Mr. WILLIAM WRIGHT wrote that from his own experience in erecting and working evaporative condensers he cannot agree with the opinion expressed in page 186, that it is necessary to stir up the steam in order to condense it more readily. An experiment was tried in this direction by inserting a small tube in the centre of the brass condensing tube, as mentioned in page 186, so as to cause the steam to pass in a thin annular film through the outer tube; but the result was disappointing, and the inner tube had to be removed. The Row indented tube he believes does not overcome the difficulty, but obstructs the passage of the steam inside, and presents awkward recesses outside for scale and dirt to be deposited on, thereby impeding the evaporative power of the tube, while the deposit would also be more difficult to remove than from the plain round smooth surface of a cylindrical tube; moreover the indents must weaken the tube, and render it more liable to collapse under vacuum or burst under pressure. The way in which the test of the

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Row tube was carried out, he agrees with Mr. Longridge (page 216), appears not to be quite satisfactory. No contrivance inside or outside of the tubes he thinks can improve their efficiency, which depends simply upon clean surfaces both inside and outside. The Ledward corrugated tube, Fig. 18, Plate 42, instead of obstructing the area of passage, increases the condensing surface both inside and outside, thereby giving more condensing power in the same length of tube. Although he cannot agree that the steam passes in and out of the corrugations (page 187), it certainly passes into them and is condensed there, and so draws into them after it a fresh supply of steam from the current in the tube. These recesses may also be useful for catching oil or grease until their bottom part gets filled, when the oil or grease would flow over as usual. The success of an evaporative condenser is dependent upon clean tube surfaces, clean condensing water, clean air, and freedom from obstructions. Spiral wire coils, wire netting, brass cups, or fibrous material, all require great care and attention in order to maintain a good vacuum; so also do the water distribution, the air supply, and the air pump. The plan of jointing the tubes by expanding their ends in the top boxes, and providing loose glands with rubber washers and water seal in the bottom boxes, is a good one. More ground space and more tube surface are required than is generally supposed, as is shown by the fact that he has never had any difficulty in obtaining a good vacuum with light loads, when the tubes, water, and air have been clean and plentiful.

Mr. HARRY FRASER wrote that from his experience the evaporative condenser is a successful and useful apparatus to adopt, if it is not attempted to do too much in too small a space. The oldest form erected of evaporative condensers occupied as much as about 2 square feet of floor space per I.H.P.; whereas in the modern forms with vertical brass tubes attempts have been made to get 15 I.H.P. into this space, and the results have not been so successful. There is not room enough for cleaning the apparatus when it is cramped up in such a small area. If the tubes are made of galvanized wrought-iron 3 inches diameter, and 3 inches clear space is allowed between each

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(Mr. Harry Fraser.)
tube, and 18 inches clear space between each alternate row of tubes for cleaning, as is now done in the evaporative condensers largely manufactured by his firm at Millwall, the working of the apparatus is then highly satisfactory. With this arrangement the condensation of 2 I.H.P. is obtained from each square foot of floor space occupied, which is only one quarter of the floor space for the older kinds of evaporative condensers. The air pump should be on the balanced beam principle, and the water-circulating pump should be worked off one of the beams of the air pump, so that there is only one auxiliary engine to look after for the whole working of the condenser. Fans he finds are practically inapplicable, because they would have to be of such large dimensions in order to be of any real value. The evaporative condenser is less costly than a cooling tower, and occupies less floor space, and uses less power; and he anticipates that, when greater experience has been gained with the above form of evaporative condenser, it will be largely adopted. Where condensing has to be done with scant supply of water, there must always be a certain amount of difficulty to be overcome; and the evaporative condenser seems to him to be the most likely arrangement for overcoming this difficulty, when carefully and correctly designed for the work it has to perform.

Mr. OLDHAM wrote that during the discussion the various kinds of evaporative condensers do not appear to have been sufficiently distinguished one from another. In the paper various proportions of cooling surface are given; but some refer to brass-tube vertical condensers, and others to wrought-iron and cast-iron horizontal condensers. As it is desirable that these should be clearly discriminated, the figures in Table 6 have been collected for greater convenience of comparison, partly from the paper and partly from the writer's experience. With these proportions a vacuum should be maintained of not less than 24 inches of mercury (page 244). The quantity of cooling water in circulation should be:—for condensers with cast-iron tubes and for brass-tube vertical condensers, from ten to fifteen times the weight of the steam condensed per hour; for condensers with horizontal wrought-iron or copper tubes, about five

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TABLE 6.—*Weight of Steam Condensed per hour per square foot of condensing surface in various Evaporative Condensers.*

Page	*Condensers with Horizontal Tubes, without Fans.*	Lbs. per hour.
192	Cast-Iron Plain Tubes, Plate 47	1 to 1½
	„ „ „ exposed to good steady wind	1½ to 2
192	Cast-Iron Corrugated Tubes, Ledward, Fig. 18, Plate 42 (* or 8 lbs. per hour per foot run of tube).	*1½ to 1½*
203	Wrought-Iron Galvanized Tubes, Fraser design .	2 to 2½
	„ „ or Copper Tubes, in good position on roof	2½ to 3
	Condensers with Vertical Tubes.	
200	Cast-Iron Plain Tubes, Table 2 and Plate 58 . .	1½ to 2
	Brass Tubes, without fan and exposed . . .	3 to 3½
	„ „ with fan at slow speed . . .	4 to 5
	„ „ with fan at higher speed and good water circulation . .	5 to 6

to ten times the weight of steam condensed per hour. With perfectly clean condensers the quantity of cooling water may be reduced; but the circulating pumps should be made to take the maximum quantity. Although theoretically only one lb. of water should be required for condensing each lb. of steam, yet with so small a quantity it would be impossible to ensure such an even distribution that all the tubes should be covered by the circulating water. The weather also plays an important part in the efficiency of an exposed condenser; on wet or windy days the weight of steam condensed is increased 15 to 20 per cent. The tubes of evaporative condensers are generally found to be clean inside, and with scale on the outside in proportion to the hardness of the water. Clean water should always be used.

So far from the metal of the tubes or their construction having but little to do with the efficiency of the condenser (page 209), the contrary is certainly true, inasmuch as thin wrought-iron or copper tubes are found to be of greater condensing value than thick cast-iron tubes. Moreover the weight of the condenser can be considerably reduced by the employment of either of the former.

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(Mr. Oldham.)

It is most important that the exhaust-steam inlets should be so arranged that every tube shall take its equal share of the steam. In some condensers trouble has been caused through the greater part of the steam passing through a few tubes only, while the rest of the tubes remain quite cold; suitable baffles or partitions should therefore be provided for compelling the steam to pass equally through the whole of the tubes.

The condenser mentioned by Mr. Andrews (page 217) has behaved in a peculiarly eccentric fashion, of which it is impossible to offer any explanation without a thorough investigation. These condensers do not usually present such difficulties; and several working on light loads are answering well. In the same instance probably the reason why the fan did not increase the efficiency of the condenser (page 220) was because there was no casing round the condenser; a casing should be fixed round the upper portion of the tubes, so that the air may be drawn in at the lower portion and allowed to pass up amongst them throughout their whole height.

It is highly important that the air pump be kept cool; the supplementary coolers mentioned in the paper are designed for this purpose.

The quantity of cooling water in circulation, mentioned by Mr. Williams (page 234), is erroneous, as will be seen from the proportions already given (page 252). The maximum quantity of water used by the Fraser or the Theisen condenser does not exceed twenty times the weight of steam condensed per hour; and out of this the maximum quantity of water lost by evaporation does not exceed the weight of steam condensed. In the Royle condenser the weights mentioned (page 234) were those used in an experiment.

Unfortunately no correct record has been kept of the value of coal saved, or of the interest on capital &c. (page 244). But from several condensers that are now being erected valuable information will be obtained and recorded, and when made known will probably result in other evaporative condensers being put up.

Other data which have been asked for on particular points have not hitherto been recorded; but on these it is hoped that interesting and trustworthy results will ere long be forthcoming.

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FORMAL OPENING OF THE NEW HOUSE.

The formal opening of the New Building in St. James's Park was celebrated by a Conversazione held therein on two successive evenings, 16th and 17th of May, 1899. In addition to all the members of the Institution, invitations were issued to some 750 guests, including representatives of the Government, the Universities, and the Scientific Societies of the country. A pamphlet containing a brief history of the Institution with illustrations of the new house was presented to each of the company; and the contents of the pamphlet with some additions are reproduced here for permanent record.

Brief History of the Institution and Description of the Building.

The objects of the Institution of Mechanical Engineers, which now for the first time occupies a home of its own in London, are to promote the science and practice of Mechanical Engineering in all its branches, and to enable its members to meet and to correspond, thus facilitating the interchange of ideas, and aiding in many ways the interests of the engineering profession.

The Institution, which was founded in 1847, has an honourable history. No one is now living who can state with certainty the precise way in which it originated. According to one version it was the outcome of a gathering of a few engineering friends in the house of Mr. Charles F. Beyer in Cecil Street, Manchester. By no means incompatible with this is the statement of his partner, Mr. Richard Peacock, M.P., who in August 1879 narrated his own recollection of a meeting in 1846 of six gentlemen, of whom he was one, in the house of Mr. James Edward McConnell at the foot of the

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Lickey incline on the Bristol and Birmingham Railway, near Bromsgrove. The names of those present were—Mr. Beyer; Mr. Charles Geach, banker, of Birmingham, who became the first treasurer; Mr. McConnell, locomotive superintendent of the Bristol and Birmingham Railway; Mr. Peacock, locomotive superintendent of the Manchester and Sheffield Railway; Mr. George Selby, Smethwick Tube Works, near Birmingham; and Mr. Archibald Slate, who was at that time with Mr. Selby, and became the honorary secretary. It was then and there decided to take steps for the establishment of the Institution, and to issue a circular which is recorded as follows in the first entry in the earliest minute-book kept by the Institution:—

"In the year 1846 the following circular was issued to some of the principal engineers in England.

INSTITUTION OF MECHANICAL ENGINEERS.

To enable Mechanics and Engineers engaged in the different Manufactories, Railways, and other Establishments in the Kingdom, to meet and correspond, and by a mutual interchange of ideas respecting improvements in the various branches of Mechanical Science to increase their knowledge, and give an impulse to inventions likely to be useful to the world.

We hope to have the pleasure of seeing you at a Meeting of the promoters of the above on Wednesday 7th October at 2 p.m. at the Queen's Hotel, Birmingham.

EDWARD HUMPHRYS, Messrs. Rennie's, London.
ARCHIBALD SLATE, Tube Works, Smethwick.
J. E. MCCONNELL, Bristol and Birmingham Railway.
CHARLES F. BEYER, Sharp Brothers and Co., Manchester."

In compliance with this invitation a meeting was held on 7th October 1846 at the Queen's Hotel, known also as Bacon's Hotel, which at that time adjoined the former terminus of the London and Birmingham Railway in Curzon Street, Birmingham. The building itself, with its massive stone façade and lofty entrance surmounted by elaborately chiselled embellishments, was utilised ten years later for the offices of the goods department, and still remains as a conspicuous example in Birmingham of the same style of architecture that is seen at Euston. Mr. McConnell occupied the chair; and ...t those present were:—Mr. William Buckle, Soho Works,

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Birmingham (James Watt and Co.); Mr. James Brown, Soho (James Watt and Co.); Mr. Charles F. Beyer, Atlas Works, Manchester; Mr. Edward A. Cowper, London Works, Smethwick (Fox and Henderson); Mr. Archibald Slate, Tube Works, Smethwick; Mr. John Edward Clift, Staffordshire and Birmingham Gas Works; Mr. Benjamin Cubitt, New Cross; Mr. Henry Dübs, Warrington (Tayleur's Vulcan Foundry); Mr. Edward Humphrys, Albion Works, London; Mr. William S. Garland, Soho (James Watt and Co.); Mr. Richard Peacock, Manchester and Sheffield Railway; Mr. John Ramsbottom, London and North Western Railway, Longsight, Manchester. The following were appointed a committee to draw up rules for the management of the Institution:—Messrs. Peacock, Slate, Beyer, Humphrys, McConnell, Buckle, Clift, and Cowper.

At the dinner in the evening the toasts included:—Success and prosperity to the Mechanical Engineering Institution, coupled with the name of Mr. Archibald Slate, the honorary secretary of the new Institution; the Institution of Civil Engineers, acknowledged by Mr. Benjamin Cubitt; the Memory of James Watt, responded to by Mr. Buckle; the establishment of Mr. Rennie, for which Mr. Humphrys replied; the Locomotive Manufactories of Great Britain, acknowledged by Mr. Beyer; the liberty of the Press, to which Mr. Maher responded; the health of George Stephenson, the "Father of Railways," and of Mr. Robert Stephenson, the worthy son of a worthy sire; the Railway Directors of Great Britain, acknowledged by Mr. Joseph Sanders, secretary of the Bristol and Birmingham Railway; the health of Mr. Brunel; and the healths of the chairman Mr. McConnell, and the vice-chairman Mr. Buckle.

On Wednesday 18th November 1846, the committee assembled and approved of the rules and regulations for the Institution.

On Wednesday 27th January 1847 a general meeting was held at the Queen's Hotel, Birmingham, for the purpose of forming the Institution. Mr. McConnell, occupying the chair, read a list of gentlemen who had sent answers to a circular inviting their co-operation and their consent to become Members of the Institution. On his proposal, seconded by Mr. Buckle, it was resolved "That the Institution be established, and composed of the gentlemen whose

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names he had announced." Mr. Slate having read the Rules of the Institution, which had been prepared by the committee, their adoption was carried, on the motion of Mr. George Stephenson, seconded by Mr. Beyer. Mr. McConnell moved the election of George Stephenson, Esq., as President of the Institution; and the nomination having been seconded by Mr. Cowper was carried with acclamation.

On taking the chair, the President gave an interesting account of his early days at Killingworth Colliery, where his career had commenced. On the motion of Mr. John Henderson, Smethwick (Fox and Henderson), seconded by Mr. Richard Peacock, the following were appointed to be the Vice-Presidents of the Institution: —Joseph Miller, London; Charles F. Beyer, Manchester; James E. McConnell, Wolverton. On the motion of Mr. Peter Rothwell Jackson, seconded by Mr. James Ward Hoby, the following were appointed to be the Council of the Institution:—Edward Humphrys, London; Benjamin Fothergill, Manchester; Joseph Radford, Manchester; William Buckle, Soho; Edward A. Cowper, Smethwick. On the motion of Mr. Buckle, seconded by Mr. McConnell, it was resolved that Mr. Charles Geach, of the Midland Bank, Birmingham, be Treasurer to the Institution. On the motion of Mr. Beyer, seconded by Mr. Henry Chapman, it was resolved that Mr. Slate be Secretary and Mr. Maher acting secretary to the Institution. Of the original Members who joined in constituting the Institution on 27th January 1847 the only survivor is now Mr. Richard Williams of Wednesbury.

The first meeting of the Institution for the reading of papers took place on 28th April 1847, and like the first general meeting it was held at the Queen's Hotel, Birmingham. The meetings were continued at the Queen's Hotel, then in Temple Buildings, New Street, and in the Philosophical Institution, Cannon Street, Birmingham, until 1850, when premises were acquired in Newhall Street, which formed the head-quarters of the Institution for the next twenty-seven years. After 1864 the meetings were held in the Midland Institute until 1877, when the head-quarters of the Institution were transferred to London, suitable accommodation for the staff

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and the library being obtained at 19 Victoria Street, Westminster; and by the courtesy of the Institution of Civil Engineers, the London meetings were held in the hall of that Institution. These arrangements continued in force until the current year, when, as already stated, the Institution of Mechanical Engineers entered into the possession of a new home of its own, which it is the object of this notice to describe.

Before giving this description however, something more may be said as to the growth of the Institution. The proposal to hold the Summer Meetings of the Institution in the leading centres of engineering throughout the kingdom originated in 1856 with Mr. James Fenton, who was consulting engineer to the Low Moor Iron Co. from 1851 to 1863, and was at that time a member of the Council; and through his energetic exertions the proposal was realised in September of the same year, by a meeting held for the first time in Glasgow, under the presidency of Mr. Joseph Whitworth. As one result of this new step, the number of Members of the Institution, which for the seven preceding years had remained at almost a dead level of little over two hundred, now began at once to increase at a rate of growth which has since continued to progress steadily up to the present date, as shown by the table on the next page and plotted in the diagrams in Plates 69 and 70. This meeting in Glasgow showed the engineers of the neighbourhood their own numerical strength; and led to the establishment in the following year of the Institution of Engineers and Shipbuilders in Scotland, under the presidency of Professor W. J. Macquorn Rankine. The establishment of that Institution, and subsequently of various other engineering societies in different districts, is believed to have proved ultimately beneficial to the growth and prosperity of the Institution of Mechanical Engineers. Summer meetings have been held at the following places during the last forty-three years:—Glasgow four times, Manchester four times; Newcastle, Leeds, Birmingham, Liverpool, and Paris, each three times; Sheffield, London, Dublin, Middlesbrough, and Cardiff, each twice; and once each in Nottingham, Penzance, Bristol, Barrow-in-Furness, Liége, Lincoln, Edinburgh, Portsmouth, Belfast, and Derby. In connection with the meeting at Portsmouth in 1892 the Council drew the attention of the

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Year.	Total Number of Members.	Annual Income. £	Total Invested Capital. £	Total number of Members and Visitors attending Meetings in the year.		
				Members.	Visitors.	Total.
1847	107	515				
1848	189	741				
1849	201	600				
1850	202	676				
1851	203	619				
1852	204	614				
1853	216	703				
1854	228	702				
1855	218	620				
Commencement of peripatetic Summer Meetings in 1856.						
1856	259	817				
1857	301	997				
1858	341	1,097				
1859	391	1,275				
1860	428	1,445				
1861	464	1,391				
1862	497	1,618				
1863	540	1,889				
1864	572	1,926				
1865	652	2,141				
1866	728	2,462				
1867	791	2,388				
1868	825	2,357	4,500			
1869	855	2,650	4,500			
1870	862	2,823	4,500			
1871	875	2,806	5,973			
1872	912	2,953	6,973			
1873	956	3,208	7,978			
1874	992	3,270	9,178	416	231	647
1875	1,018	3,471	10,188	434	203	637
1876	1,041	3,440	11,016	357	117	474
1877	1,075	3,641	11,869	521	168	689
Removal from Birmingham to London in 1877.						
1878	1,140	3,801	8,868	394	263	657
1879	1,178	3,782	8,868	441	314	755
1880	1,210	4,085	8,868	414	269	683
1881	1,276	4,248	9,217	485	279	764
1882	1,370	4,660	9,617	509	270	779
1883	1,440	4,690	10,617	397	189	586
1884	1,554	5,094	10,617	887	248	1,135
1885	1,640	5,330	11,967	607	362	969
1886	1,674	5,701	13,467	620	370	990
1887	1,741	5,753	15,469	554	260	814
1888	1,806	6,121	16,490	442	244	686
1889	1,858	6,260	17,489	418	246	664
1890	1,943	6,784	18,888	518	236	754
1891	2,077	7,212	20,287	628	273	901
1892	2,147	7,192	22,537	502	299	801
1893	2,157	7,030	24,787	426	265	691
1894	2,222	7,081	26,558	620	331	951
1895	2,271	7,274	27,340	546	363	909
1896	2,360	7,388	*34,979	488	334	822
1897	2,490	7,906	†37,619	677	308	985
1898	2,680	8,496	‡37,947	910	331	1,241

* Capital, 1896 { Invested £18,102 / House £16,877 } = £34,979.

† Capital, 1897 { Invested £32,183 / House £30,436 } Less Debentures £25,000 = £37,619.

‡ Capital, 1898 { Invested £15,403 / House £47,544 } Less Debentures £25,000 = £37,947.

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Members to a feature which had been noted with much gratification, namely that the cost of the necessary arrangements was distributed among the Members for whose benefit they were made: thereby showing for the first time how the Members may be enabled to enjoy the advantage of meeting in various localities, free from all misgivings of their visit assuming in any degree the aspect of a visitation. The same considerations clearly enlarge the range of localities in which future meetings of the Institution may advantageously be held.

A highly important branch of the work of the Institution has been that of the Research Committees, whose duty it is to investigate and report upon certain selected questions relating to mechanical engineering, which cannot well be adequately treated in the course of ordinary practice. Amongst the subjects thus taken up are the strength of riveted joints, the hardening and tempering of steel, friction at high velocities, marine-engine trials, the value of the steam-jacket, gas engines, and the properties of alloys. The first Research Committee was appointed in 1879, and since that date upwards of £4,000 has been spent in experimental research by the Institution; while the value of the personal work which has been performed—in all cases gratuitously—by the numerous members who have constituted the various research committees must be placed at a vastly larger sum.

The Institution at present possesses a library of about 10,000 volumes; and now that ample accommodation has been secured for its extension, it is hoped that this number may be rapidly increased. The Proceedings of the Institution fill over 50 volumes; Transactions are exchanged with 103 societies, 47 inland and 56 foreign; and 53 volumes are presented annually to 26 colleges and libraries.

The new house of the Institution has been erected on a unique site. The façade overlooks a Royal Park, with a magnificent view over the Horse Guards' Parade and the ornamental waters of St. James's Park. Around are to be seen the more ornate of the Government Offices—the Foreign Office, the Office of Works, and the new Admiralty Buildings.

The following description of the building has been prepared by the architect, Mr. Basil Slade:—

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"The house has been about two years in building, and stands on a gravel foundation in running water about 22 feet below the ground level. Some trouble was experienced in laying the concrete foundation, as the effect of the tides in the Thames was appreciably felt; pulsometer pumps were used, and massive walls of concrete, 7 feet wide, were put in, these walls being traversed by strong terra-cotta pipes to permit of the easy flow of water from the centre of the building.

"The basement floor of the house is practically an asphalt-lined tank resting on the top of concrete legs. The building is perfectly dry, and no settlement cracks have been as yet perceived, nor are any anticipated.

"The building has been designed to suit the increasing scientific and literary requirements of the Institution and its official staff.

"Entering the house from Birdcage Walk, which is a continuation of Great George Street, Westminster — the home of kindred Institutions—the entrance door is sheltered by a lofty Portland stone portico supported by Ionic columns. To the left is a bold tower, in which the staircase and lift rise to the upper floors. The exterior façade is of renaissance treatment in Portland stone and red brick.

"The entrance hall and staircase are treated with Hungarian oak panellings, floorings, arcadings, balusters, newels, &c., French polished, and surmounted by plain Persian red walls and enriched ceilings.

"Immediately opposite the entrance is the main doorway into the lecture theatre. This room has a Georgian ceiling with central glass dome, from which it is lighted by day, and by night from a cluster of incandescent electric hanging lamps. The floor is constructed of movable platforms, which can be arranged to form terraces or a level floor, as desired. The ornamental ceiling is hung from the top and free from the walls, and has a bold cove, behind which the wall-diagram rollers are hidden. It is trusted this arrangement of ceiling will give good acoustic results, and prevent any echo.

"On this floor, and approached by a broad corridor, is the council chamber, a room treated with a more Jacobean freedom, with an oaken ribbed star-pattern ceiling and bold cove to the cornice.

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"On the entresol floor below is found the marble tea room or withdrawing room, running under the full length of the entrance hall. This room has been lined and decorated with costly marbles throughout; floors, walls, arcadings, and access staircases have been treated with both new and rare stones. The treatment is of latter date, in style following the Italian. The pilasters are of antique sienna with statuary white caps and bases; the surbase is of dark dove with dado of cippolino and verte antique plinth. The panels are picked Mexican onyx, arranged to show the veining to best advantage, with delicate outline or border of pale dove with pavonazzi ground; the whole surmounted with a light statuary moulding and cippolino frieze. The ceiling is kept simple in design, with a few lines of gold to enhance the contrast of the richly coloured walls. The flooring is of piastraccia and dark grande antique squares. The tea room is served by a kitchen and pantry adjoining.

"On the same floor is to be found the principal lavatory, also treated in marbles, teaks, &c.

"The space under the lecture hall is occupied by two floors of extensive area with annexes for the storage of 'Proceedings' and other papers, amply large enough to provide accommodation for many years to come.

"On the basement floor are to be found the boiler room, ventilation ducts, and general electrical mechanical accessories.

"Re-ascending the stairs, above the entrance hall is the reading and smoking room—a room all in white of a simple Georgian character. On the same floor are the secretarial offices and galleries of the lecture hall.

"The fine and light hand-wrought ironwork to the staircase and lift shaft deserves special notice.

"The whole of the floor above is occupied with the library—a lofty apartment with annexes and book-galleries. A bold cove and pendentive ceiling is brought forward over the book-cases, giving the appearance of the books being recessed in the walls. The library is treated in the Elizabethan style, Hungarian picked oak being used throughout. The galleries are supported by bold cantilever oak modillions and Ionic columns and caps standing on a table-height

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shelf. Bastard statuary pilasters and oaken impost and arcades separate the main library from the annexes.

"The remainder of the building is occupied with offices for the staff, a room for the meetings of Graduates, spacious drawing and diagram rooms, and apartments for the housekeeper.

"The building is lit throughout with electricity; and the same agent is used for working the lifts, clocks, ventilation fans, and power for the exhibition of models in the theatre.

"The principal rooms are ventilated on the plenum system. The fresh air is drawn in by an electrically-driven fan, 4 feet diameter, from the north area in the park, and cleansed over fibre screens automatically washed with water, then passed over a radiation coil and along a duct up to the various apartments, whence the vitiated air is forced up vents to the top of the building."

The acquisition of the site and the erection and equipment of the house have been carried out under the supervision of the Presidents holding office since 1894, and of a House Committee consisting of Members of Council, who have devoted a great amount of time and trouble to the work.

The present notice is accompanied by a series of plans and perspective views which will give an excellent idea of the character of the building.

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MEMOIRS.

William Carpmael was born in London on 1st December 1832, and was educated at Clapham Grammar School under Rev. Charles Pritchard, who afterwards became Savilian professor of astronomy at the University of Oxford. In 1850 he entered the office of Messrs. Carpmael and Co., patent agents; and thenceforth till within a short time of his death he devoted the whole of his time to the practice of his profession. On the death of his father in 1867 (Proceedings 1868, page 14) he became senior partner in the firm. Taking always a great interest in questions relating to patent law and practice, he gave evidence in 1872 before a select committee of the House of Commons on patent law; and in 1883 he took part in a deputation to the then President of the Board of Trade, with the result that material alterations were made in the patent act at that time under consideration, which afterwards became law. He also took a keen interest in the status of the profession, and was one of the founders of the Institute of Patent Agents. From its foundation in 1882 he was a member of the Council, and he was elected President in 1886 and 1887. When the Institute was incorporated by royal charter in 1891, he remained a member of the Council. He contributed to the transactions numerous papers on professional subjects. For some years his health had been failing, and he was finally compelled to retire from practice. He died on 29th May 1899 at the age of sixty-six. He became a Member of this Institution in 1866.

James Charnock was born on 18th March 1851 at Dukinfield, near Manchester. He received his education from 1857 to 1868 at St. John's Schools, Dukinfield, and in the science and art classes of the Stalybridge Mechanics' Institute while learning his trade at

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Messrs. Sidebottoms, cotton spinners, of Stalybridge, who occasionally made their own machinery. In 1868, at the early age of sixteen and on the recommendation of Messrs. Platt Brothers of Oldham, he went to Russia, being engaged by Messrs. De Jersey and Co. of Manchester to superintend the erection and working of special machinery in cotton mills, when the industry was in its infancy in that country. With this firm he made successive contracts up to 1879, all at the Kranholm mills of Messrs. L. Knoop, at Narva, Esthonia, then as now the largest cotton spinning and manufacturing mills in the world. In 1879 he became manager of the Ismailova mills near Moscow. In 1881 he was engaged to build and manage new mills at Nicholski near Moscow for Messrs. Vicoul, Morosoff and Sons, then a small weaving and dyeing firm. Under his management, embracing as it did the construction of the mills, the housing and provisioning of the workpeople, and the supervision of forests and turf fields, the concern developed rapidly, until at the present time it is one of the most successful in Russia and one of the largest in the world, employing nearly 12,000 hands in cotton spinning, weaving, dyeing, and finishing, and in forestry. From 1883 he was a partner in the firm, who now house some 22,000 persons—men, women, and children—besides providing for the lodging of another 9,000 round the district. He was also one of the original founders and a director of the Savina Vigogne cotton spinning and weaving mills of Messrs. Vicoul, Morosoff, Ivan Poliakoff and Co., employing about 3,000 workpeople. For the recovery of his health, which had suffered from overwork, he had made a journey to the Mediterranean, but without deriving much benefit therefrom; and was on his way to London, when he succumbed to acute peritonitis in Moscow, where he died on 16–28th May 1899 at the age of forty-eight. He had served his firm for some eighteen years, and was recognised as one of the principal authorities on the cotton trade in Russia. He became a Member of this Institution in 1895.

Captain HENRY FRANCIS GAYNOR was born in 1864. He received his education from 1878 to 1882 at the Royal Naval School,

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New Cross; from 1882 to 1884 at the Royal Military Academy, Woolwich; and from 1884 to 1886 at the School of Military Engineering, Chatham. His studies were specially directed to mechanical engineering, and in 1884 he received his commission in the Royal Engineers. During four months in 1886 he was engaged in superintending screw-pile driving at the Royal Arsenal, Woolwich; and then spent one year 1886–87 in the Elswick Works of Sir W. G. Armstrong, Mitchell, and Co., where his time was divided between the foundry, fitting shop, smiths' shop, and ordnance drawing office. From 1887 to 1890 he was posted to the 8th (Railway) Company of Royal Engineers, Chatham. In 1890 he was sent to Singapore, where he remained till 1893 in charge of the erection of gun emplacements and pivots for 10-inch breech-loading guns; and was also appointed inspecting officer of machinery. From 1893 to 1898 he was on the instructional staff of the School of Military Engineering, Chatham, to instruct in steam engineering; and was appointed also to take charge of the Royal Engineer workshops at Chatham, including foundry, fitting, smiths', machine, pattern-makers', and wheelers' shops. On leaving this position he passed for the Staff College, Camberley, in August 1898. His death took place on 27th June 1899 at the age of thirty-five, from an accident on the previous day, when his horse bolted and threw him against a tree. For some years past he had devoted much time to the invention of an automatic sight, in which the means of correcting for rise and fall of tide were both ingenious and practical. He became a Member of this Institution in 1895.

MANASSAH GLEDHILL was born at Huddersfield on 15th December 1826. As a youth he developed a strong natural taste for mechanics and engineering, and studied closely to instruct himself in the various branches. He served his time with Messrs. Parr, Curtis, and Madeley, engineers and machinists, Manchester; and after working in one or two other shops he obtained employment in September 1852 as a turner in the works of Sir Joseph then Mr. Whitworth in Chorlton Street, Manchester. Mr. Whitworth was at that time engaged in developing his plan of hexagonal rifling

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for the bore of heavy cannon; and the first gun on that principle Mr. Gledhill succeeded in satisfactorily rifling in the lathe himself, which in those days was a feat of considerable skill and difficulty, and was personally acknowledged by Mr. Whitworth. In October 1858 he was appointed foreman, and in 1863 was made works manager of the gun, ordnance, and steel departments, being associated with Sir J. Whitworth's early experiments in artillery at Shoeburyness and Southport; and was engaged on working out the flat-headed shot which penetrated a 4-inch wrought-iron armour-plate attached to the side of the "Alfred." The shot was fired from a 68-pounder cast-iron gun rifled on the Whitworth hexagonal plan, and was driven through the plate and entered the planking of the ship's side. This was the first instance of the penetration of a 4-inch armour-plate by solid shot, and from it dates the use of steel projectiles for that purpose. He had also much to do with the development of the fluid-compressed casting process for steel ingots, whereby steel is still largely manufactured by the firm. His most important work was the origination of the hydraulic forging press for forging heavy steel ingots, which forms one of the most valuable modern developments in engineering. His perfecting of the hydraulic forging press revolutionized the manufacture of large ordnance and marine forgings, which previously it had not been possible to make by steam hammers. Owing to the comparative ease with which large gun tubes and forgings can be produced and supplied by the press, the designs of heavy guns have in recent years undergone a complete change; they are now made in a minimum number of forgings, thereby greatly increasing the strength of the gun in all directions. He had also devised many improvements in presses, guns, projectiles, marine shafting, and various machinery; and a hydraulic forging press of 12,000 tons pressure, the largest yet made, was nearing completion at the time of his death. From November 1880 he was managing director of Sir Joseph Whitworth and Co. The removal of their works from Chorlton Street to their present site at Openshaw near Manchester was carried out largely under his supervision in 1880. In 1896, when the amalgamation of the firm with that of Sir W. G. Armstrong, Mitchell, and Co.

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took place, he became a director of the joint concern, and retained his position as managing director of the Openshaw works, though failing health abated his active part in the administration. His death took place at his residence, Birchfield, Rusholme, Manchester, on 13th September 1898, in the seventy-second year of his age. He was a justice of the peace for the county of Lancaster. He became a Member of this Institution in 1887.

JOHN HAWTHORN KITSON was born at Leeds on 17th May 1843, being the third son of Mr. James Kitson, senior partner in the firm of Kitson, Thompson, and Hewitson, Airedale Foundry, Leeds. He received his second name after his father's friend, Mr. Robert Hawthorn (Proceedings 1868, page 15). After being educated at University College School, London, and graduating B.A. in 1863 at the University of London, he entered the Airedale Foundry, and worked through the various departments; and in 1866 became partner with his father, upon whose retirement in 1876 he was joined in the re-construction of the firm by his brother, now Sir James Kitson, Bart., by Mr. Thomas Purvis Reay, and later by his nephew, Mr. E. Kitson Clark. For thirty-six years he applied himself exclusively to the management of the engine works; and during this period he was actively concerned in the consideration of the design and material suitable for nearly all classes of locomotive engines, burning all kinds of fuel, and under all conditions of climate and permanent way. Possessing a remarkable memory, he was able to recall with accuracy details of locomotive design and dimensions, and incidents of locomotive history; and thus would attractively illustrate his intimate acquaintance with the construction and development of the locomotive engine. In the formation of the engineering employers' federation in 1897 he took an active part, and was chairman of the Leeds section; and was also a member of the emergency committee. He became a Member of this Institution in 1868, and was a Member of Council from 1880 to 1884. In 1875 he became a Member of the Institution of Civil Engineers. Having long suffered much from rheumatism, he died at his residence, Elmet Hall, near Leeds, on 21st May 1899, at the age of fifty-six.

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HENRY MAUDSLAY was born in Lambeth on 15th June 1822, being the eldest son of Mr. Thomas Henry Maudslay, engineer, and grandson of Henry Maudslay, the celebrated mechanical engineer, who died in 1831 and was buried in Woolwich churchyard. In his early connection with his father's firm, Messrs. Maudslay, Sons, and Field, he was employed in setting up machinery in Paris for a government tobacco manufactory; and subsequently in the same work in Portugal. In connection with the latter he was created by the King of Portugal a Chevalier of the Order of Christ, in recognition of his personal services. Afterwards he was engaged upon work connected with docks at Malta, before that department had been taken over by the government. Otherwise his professional career was confined to the superintendence of the works at Lambeth, and to trial trips of steamers. Subsequently he spent much time in Palestine, and at his own expense carried out some important excavations in Jerusalem, besides rendering much assistance to the Palestine exploration fund. A large portion of a paving which he discovered in Jerusalem he presented to St. Paul's Cathedral; and another portion to Freemasons' Hall. His death took place in Westminster on 18th July 1899 at the age of seventy-seven. He became a Member of this Institution in 1853, and was a Member of Council in 1855–6, and a Vice-President from 1857 to 1867. During these years he took an active part in the discussions at the meetings, at which he frequently occupied the chair. He was also for fifty years a Member of the Institution of Civil Engineers.

HENRY SIMON was born in Brieg, Silesia, on 7th June 1835, his father being a business man, a county magistrate, and a director of one of the earliest German railways, and his mother an authoress of some distinction. His uncle, Heinrich Simon, having as a leading member of the Prussian parliament taken a prominent part in the revolution of 1848, was compelled to leave Brieg, and was followed by his nephew to Zurich, where the latter attended the cantonal public school. In 1854, at the age of nineteen, he entered the University of Breslau; and subsequently returning to Switzerland studied engineering at the Swiss Federal Technical College, Zurich,

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where he obtained the engineering degree in 1859. He then went to Berlin, to go through his period of military service, first in the artillery, and afterwards in the guards. On the completion of this duty, he was engaged as a draughtsman by Messrs. Rohrig, Rohrig, and König at Magdeburg, who were manufacturers of water motors, turbines, and machinery for sugar works. In 1860 he came to England, and was appointed resident engineer for railway contracts in Russia by Messrs. Jametel of Manchester, for whom he spent the greater part of 1861–2 in Russia on the railway between Warsaw and Wilna, superintending the execution of various works for a distance of about 300 miles. During 1863–4 he made business journeys in Italy and France. Coming to England again, he established himself as a consulting engineer in Manchester, where he became naturalized as a British subject. Nearly the whole of 1867 he spent in Paris in connection with the English section of the International Exhibition of that year. Subsequently he was actively engaged in the supply of locomotives, rails, wheels and axles, and other material to Austrian, Rhenish, and other continental railways. His mechanical training early led him to realize the defects of the old process of flour milling; and he took up in its infancy the plan of roller milling now adopted in nearly all civilised countries, whereby the production of flour has been cheapened and increased. Although originally no better clue was placed in his hands than a crude three-high roller-mill, which performed to advantage some of the work previously done by stones, he was fully convinced thereby that the principle underlying the use of rollers would revolutionize the milling industry; and for many years almost all his energy was devoted to the development and application of this principle. From 1879 to 1897 he took out nearly thirty patents, dealing principally with the three most important processes in flour milling, namely grinding, purifying, and dressing; and also with the method of cleaning wheat in preparation for grinding, by washing and drying it. The last constituted an epoch in flour milling, and the advantages thereby gained were equal in importance to those resulting from the substitution of rollers in place of stones. On the subject of roller milling he contributed a paper to the Institution of Civil Engineers

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in 1882 (Proceedings, vol. lxx, page 191), and another to this Institution in 1889 (Proceedings, page 148). The first complete roller-mill which he fitted up in England without the use of stones was for Mr. Arthur McDougall of Manchester in 1878, and in Ireland for Messrs. E. Shackleton and Sons of Carlow in 1879; the first automatic roller flour mill in England was for Messrs. F. A. Frost and Sons of Chester in 1881. These were soon followed by larger mills in Leeds, London, Leith, Hull, York, and elsewhere; and by the largest of all in Rio de Janeiro, which formed the special subject of his paper in 1889. He also introduced with much success the Simon-Carvès coke ovens, by which the loss of ammonia and tar by-products is saved, as well as the loss entailed in vegetation destroyed upon the land that was laid waste by the sulphurous smoke emitted from the short chimneys of the ordinary coke ovens; the plan was first carried out on a large scale in 1882 at the extensive collieries of Messrs. Pease and Partners in the county of Durham, and has since been adopted in many other places. Other inventions which he improved and introduced into this country were the Chaudron method of sinking shafts, the Lehmann hot-air engine, and the Galland plan of pneumatic malting. He was the prime mover in the erection of the Manchester Crematorium (Proceedings 1894, page 438), of which he was the chairman; his design of the furnace there employed has since been adopted for the municipal crematorium at Shanghai, and also for that at Hull. He was the first chairman of the Manchester Labourers' Dwellings; and more recently was one of the originators of the Manchester Pure Milk Supply. In 1895 he endowed the Henry Simon professorship of German literature in Owens College, Manchester, besides contributing munificently to the establishment of a new laboratory there. He became a Member of this Institution in 1871, and was also a Member of the Austrian Society of Engineers and Architects, and of the French Society of Civil Engineers. His death took place at his residence at Didsbury, Manchester, on 22nd July 1899, at the age of sixty-four.

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SECCHI, L., elected Associate Member, 4.
SHAWCROSS, G. N., elected Associate Member, 146.
SHEFFIELD, F. G., elected Associate Member, 4.
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SMITH, F. S., elected Associate Member, 4.
SMITH, G. R., elected Associate, 5.
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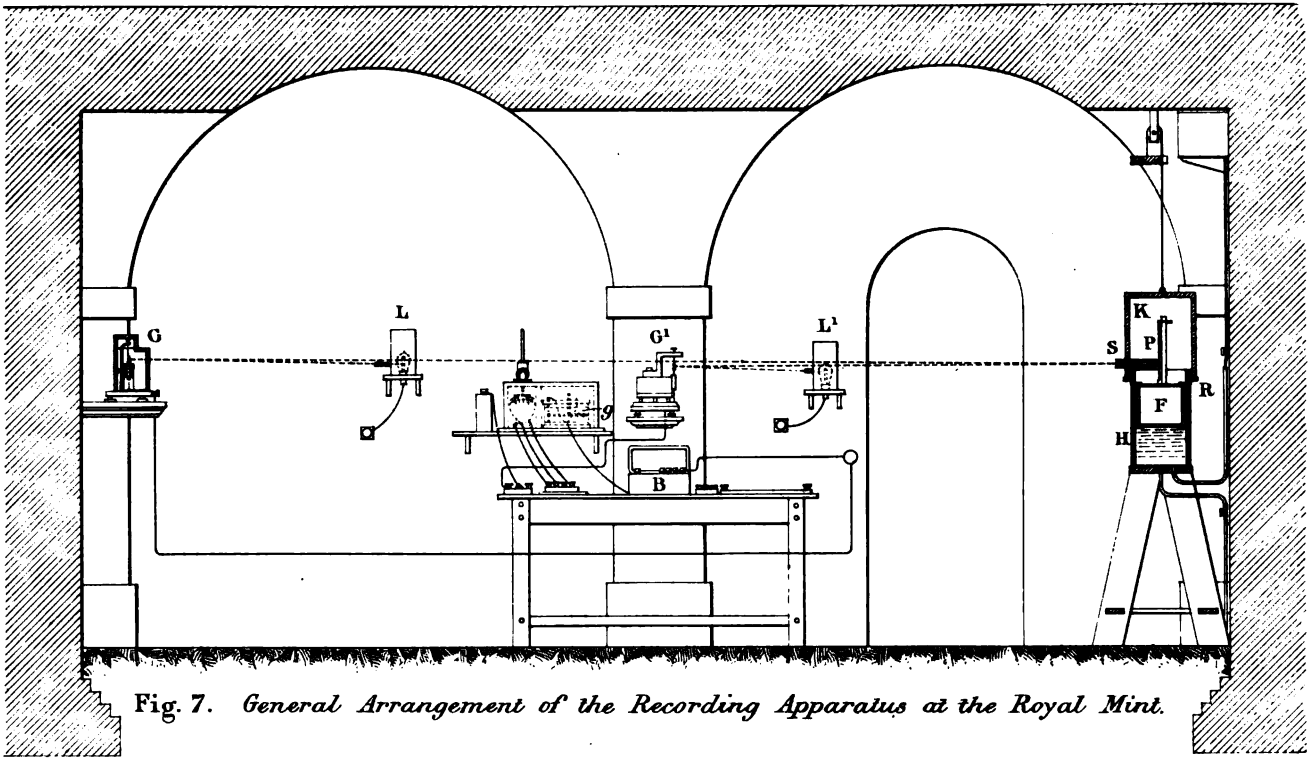

Fig. 7. *General Arrangement of the Recording Apparatus at the Royal Mint.*

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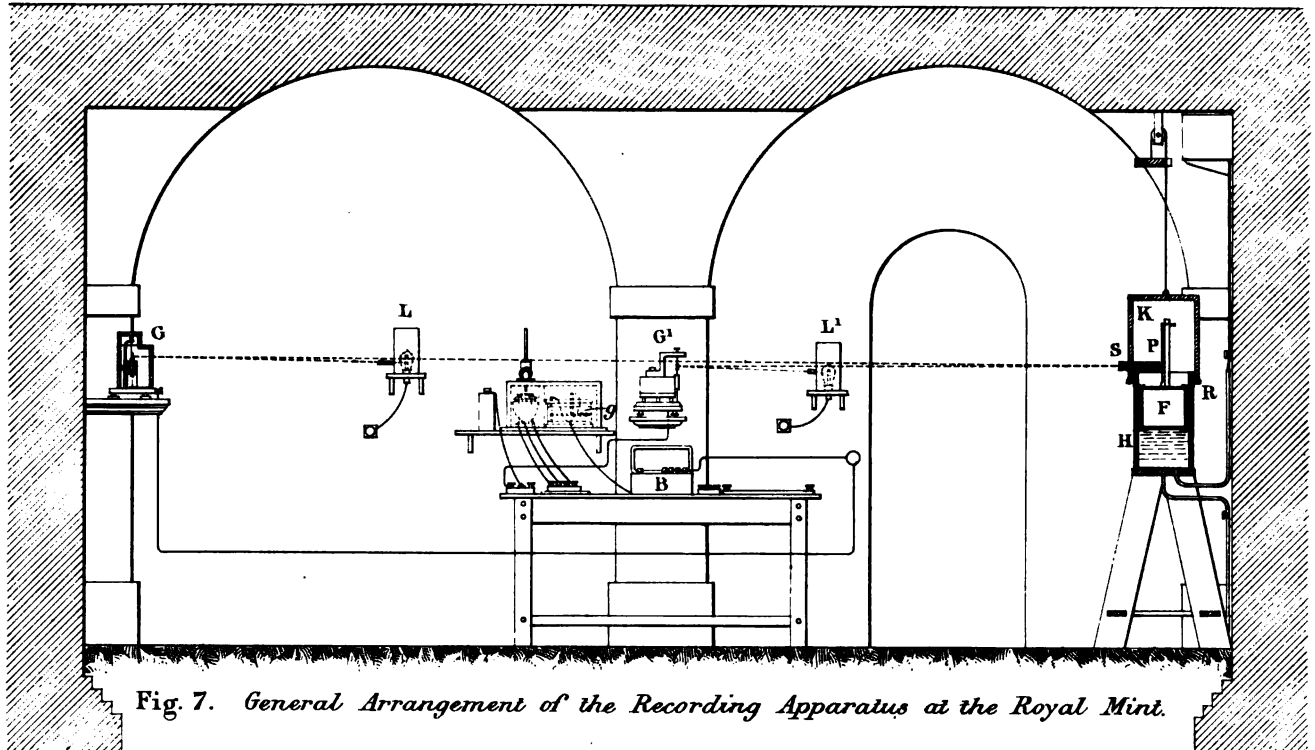

Fig. 7. *General Arrangement of the Recording Apparatus at the Royal Mint.*

Plate 1.

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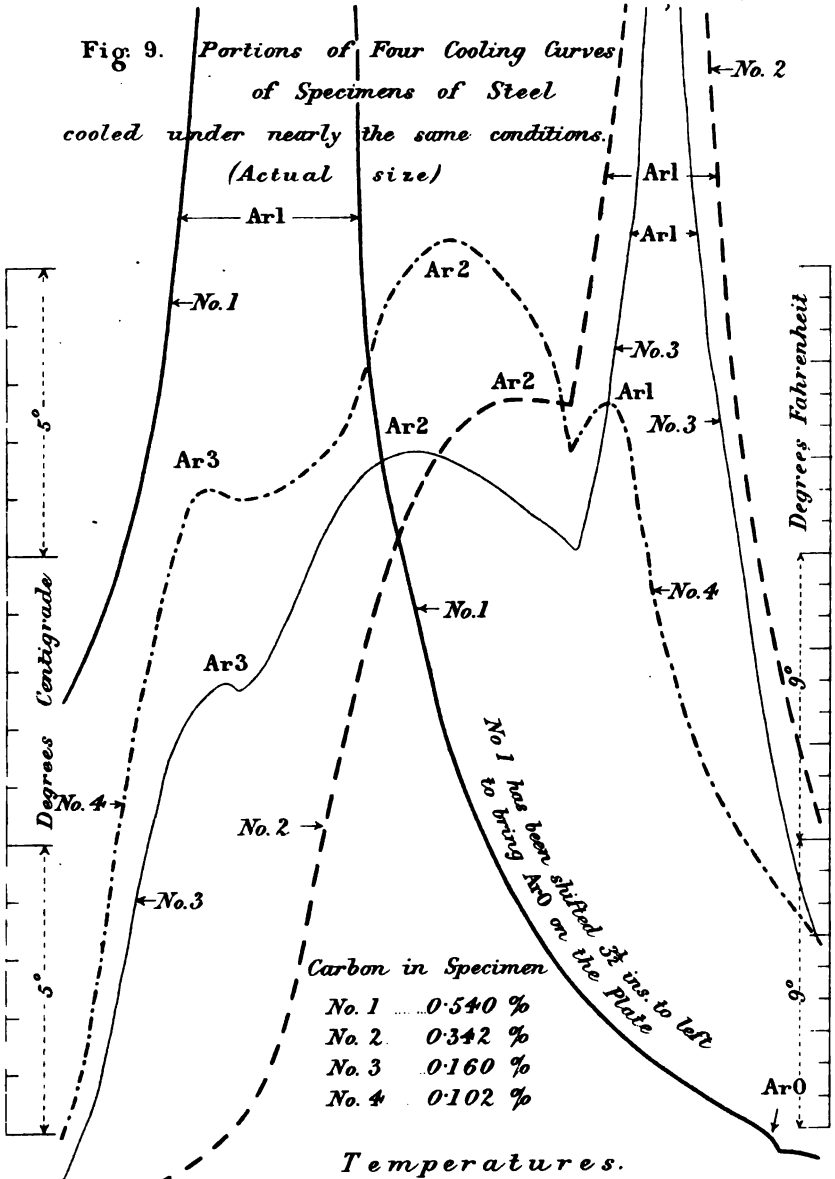
Fig. 9. *Portions of Four Cooling Curves of Specimens of Steel cooled under nearly the same conditions. (Actual size)*



Temperatures.

	No. 1.		No. 2.		No. 3.		No. 4.	
	C.	F.	C.	F.	C.	F.	C.	F.
Ar0	580°	= 1,076°	—	—	—	—	—	—
Ar1	690°	= 1,274°	690°	= 1,274°	690°	= 1,274°	690°	= 1,274°
Ar2	733°	= 1,351°	767°	= 1,412°	767°	= 1,412°	767°	= 1,412°
Ar3	—	—	—	—	838°	= 1,540°	862°	= 1,583°

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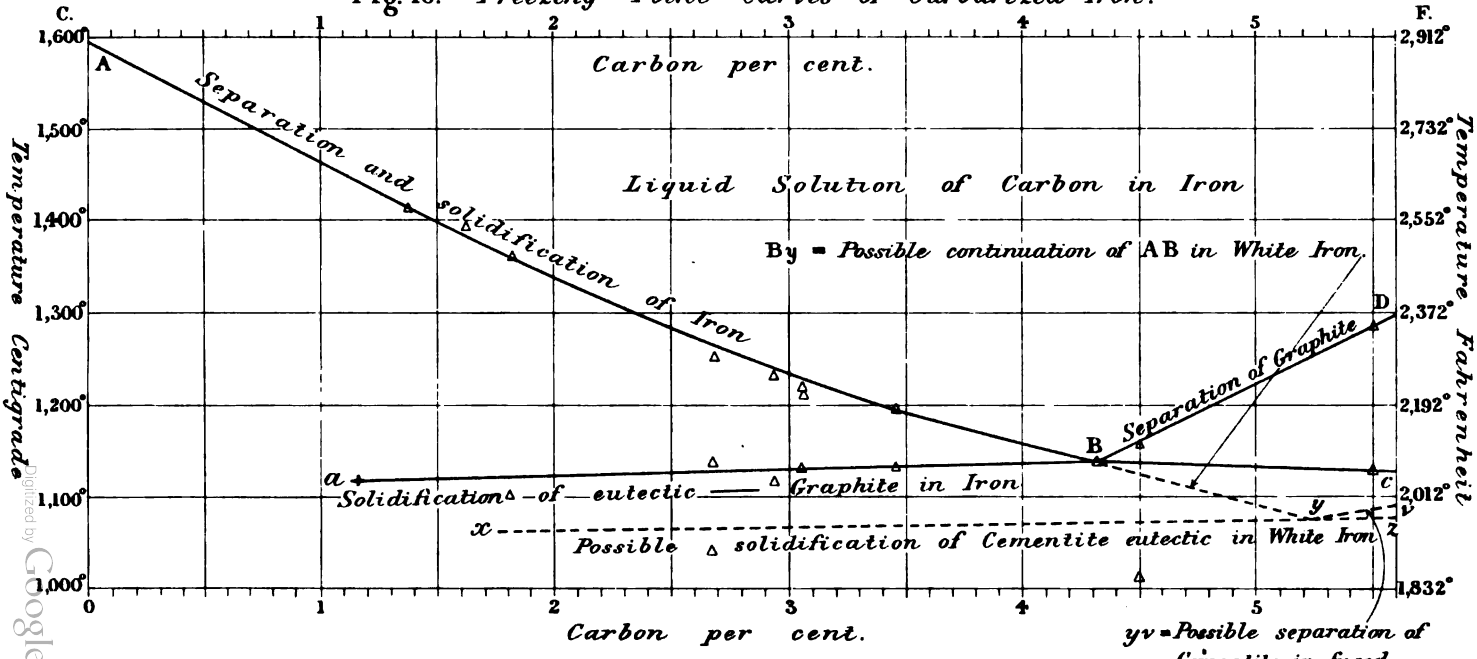
Fig. 10. *Freezing-Point Curves of Carburized Iron.*



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See continuation in Plate 5.

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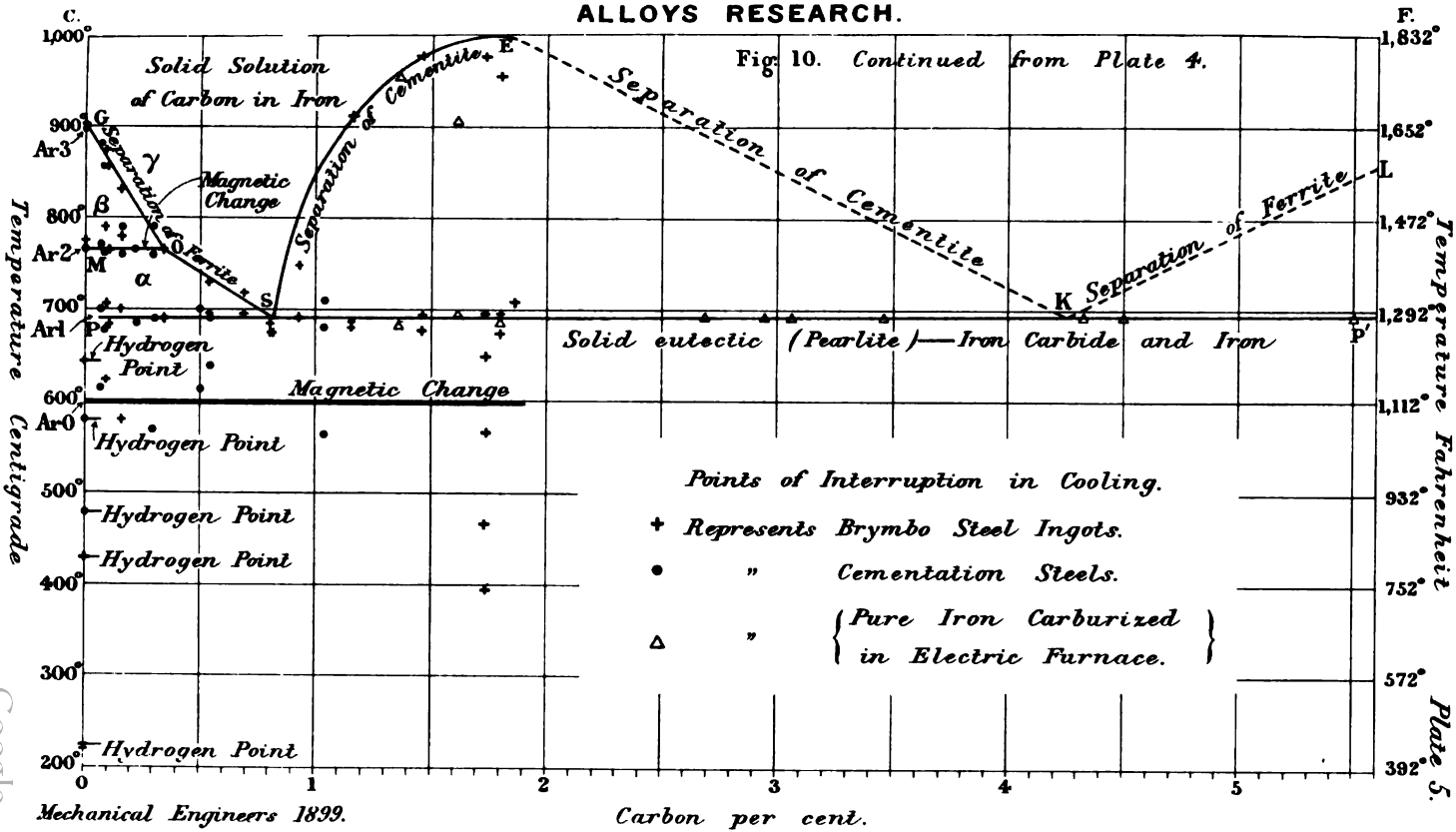

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Typical Photo-Micrographs of Slowly Cooled Iron and Steel.

Fig. 11. × *140 diams.* Fig. 12. × *850 diams.*

Iron containing 0·05% Carbon.

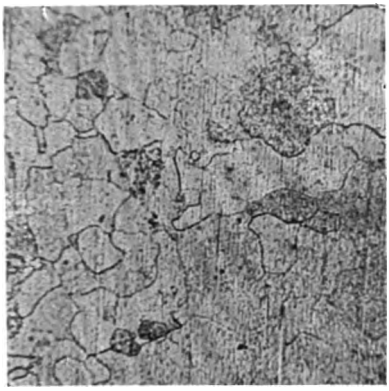


Fig. 13. *Rail Steel.*
0·33 C. 0·69 Mn. × *140 diams.*

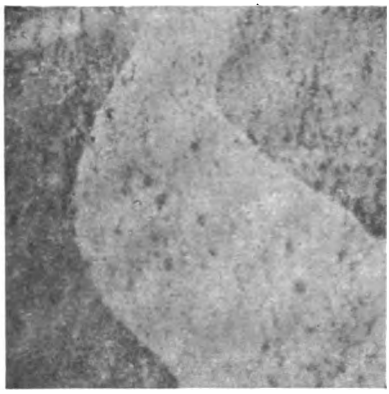


Fig. 14. *Rail Steel.*
0·36 C. 1·009 Mn. × *140 diams.*

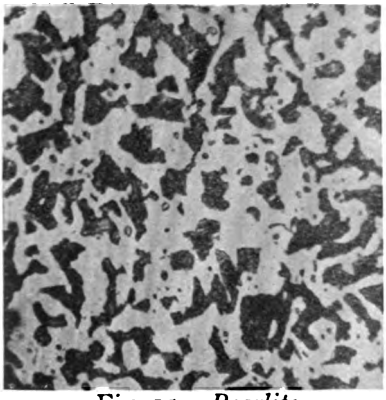
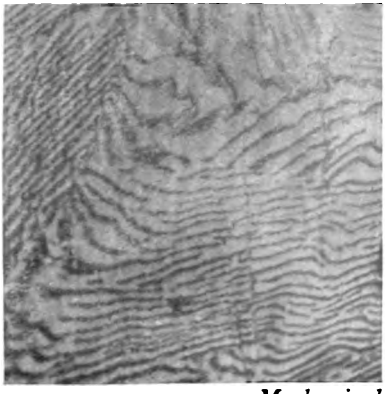
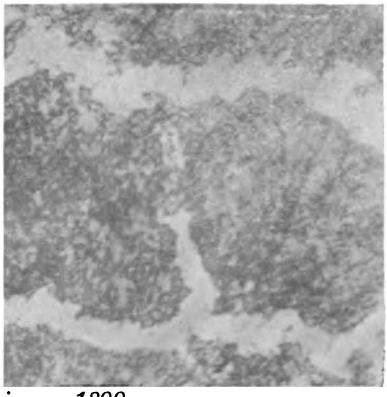


Fig. 15. *Pearlite.*
0·82 C. very little Mn. × *850 diams.*

Fig. 16. *Cementite and Pearlite.*
1·4 C. × *850 diams.*





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Typical Photo-Micrographs of Steel.

Fig. 17. *Slag Flaw in Rail.*
0·27 C. 0·71 Mn. × 640 diams.

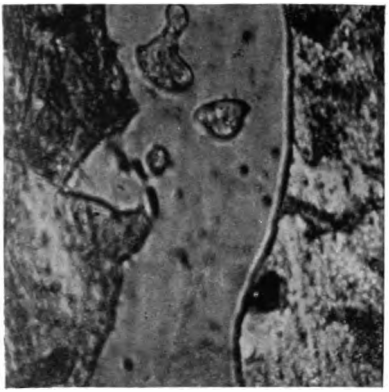


Fig. 18. *Troostite, Martensite, & Ferrite.*
0·54 C. × 850 diams.

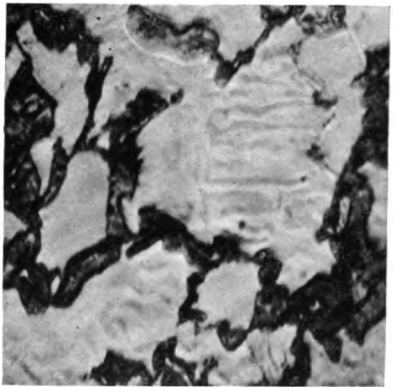


Fig. 19. *Quenched in Water.*
0·54 C. Martensite × 850 diams.

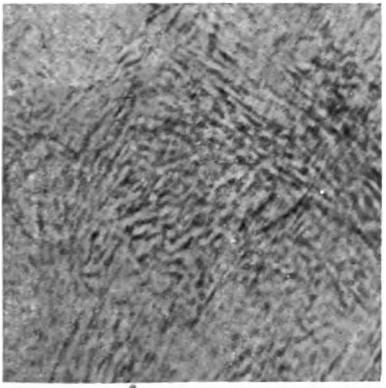


Fig. 20. *Tempered Structure.*
0·54 C. × 850 diams.

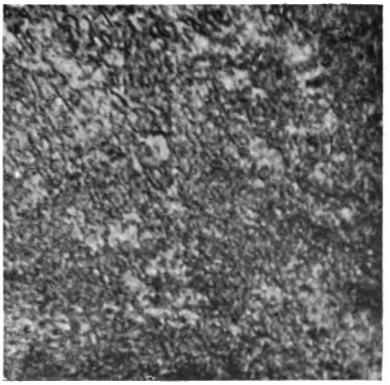
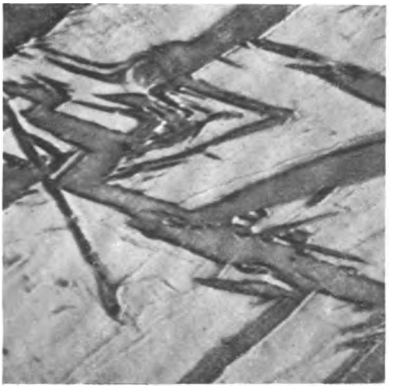


Fig. 21. *× 60 diams.*
Austenite and Martensite. 1·8 C.

Fig. 22. *× 850 diams.*



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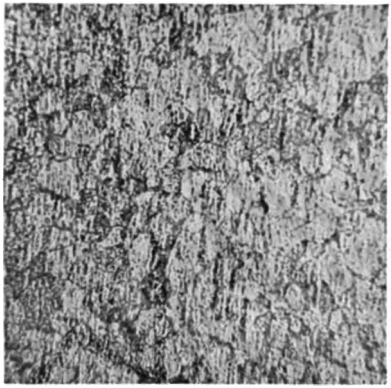
Slowly Cooled Steels.

Fig. 23. × *140 diams.* Fig. 24. × *850 diams.*

Cementation 1.A. 0·07 C.



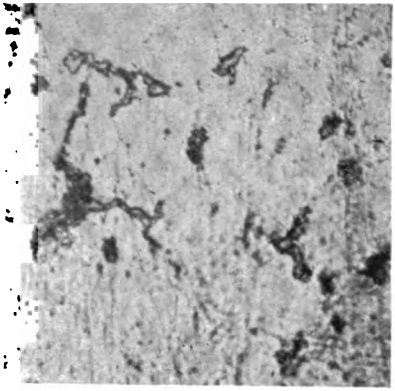
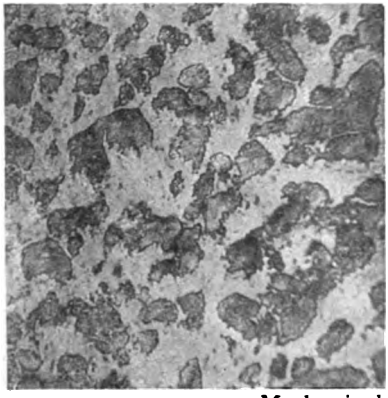


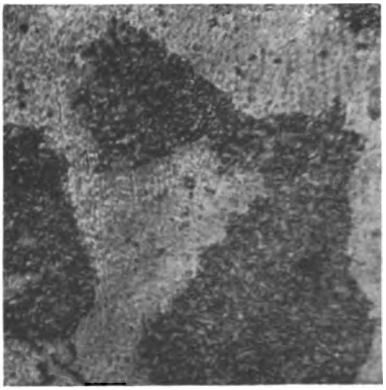
Fig. 25. × *140 diams.* Fig. 26. × *850 diams.*

Brymbo No. 21. 0·097 C.

Fig. 27. × *140 diams.* Fig. 28. × *850 diams*

Cementation A.A. 0·218 C.





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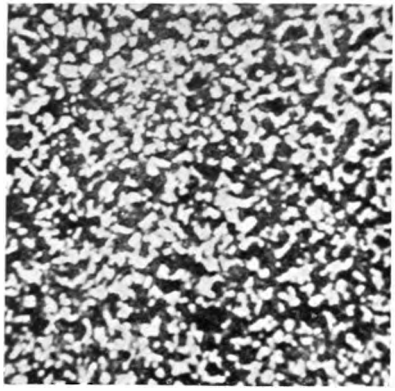
Slowly Cooled Steels.

Fig. 29. × *140 diams.* Fig. 30. × *850 diams.*

Cementation 1.C. 0·300 C.



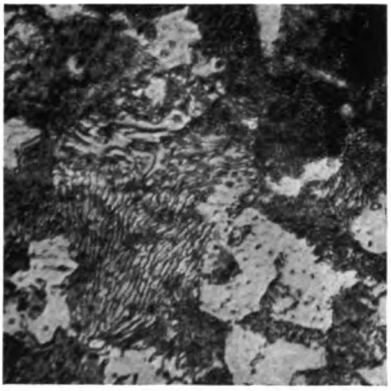


Fig. 31. × *140 diams.* Fig. 32. × *850 diams*

Brymbo No. 14. 0·342 C.

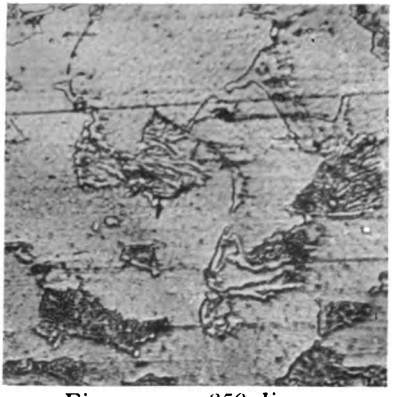
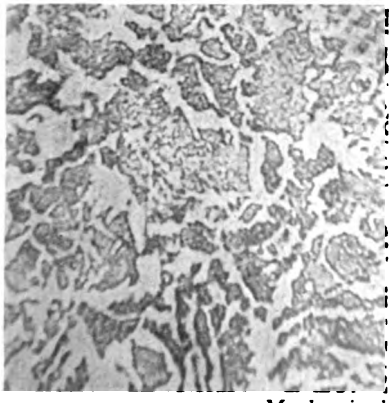
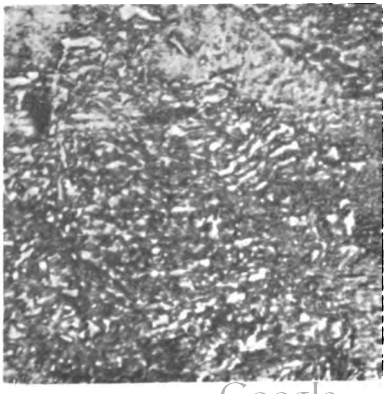


Fig. 33. × *140 diams.* Fig. 34. × *850 diams.*

Brymbo No. 12. 0·540 C.





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Slowly Cooled Steels.

Fig. 35. *Brymbo No. 11.*
0·690 C. × 140 diams.

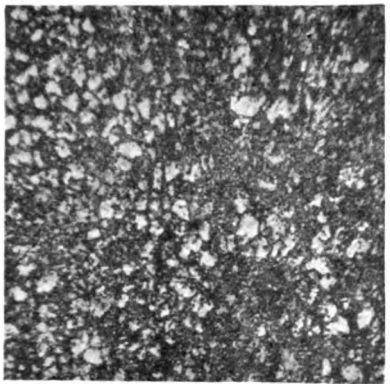


Fig. 36. *Cementation 1.D.*
0·552 C. × 850 diams.

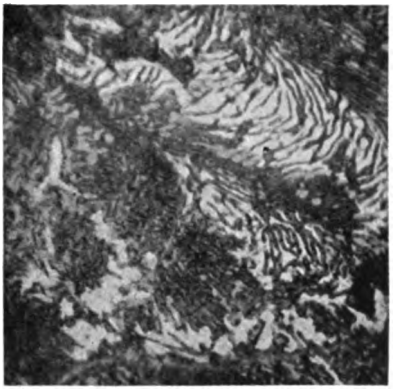


Fig. 37. *Brymbo No. 10.*
0·821 C. × 140 diams.

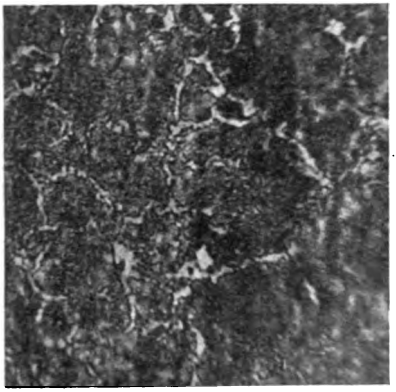


Fig. 38. *Die Steel.*
0·820 C. × 850 diams.

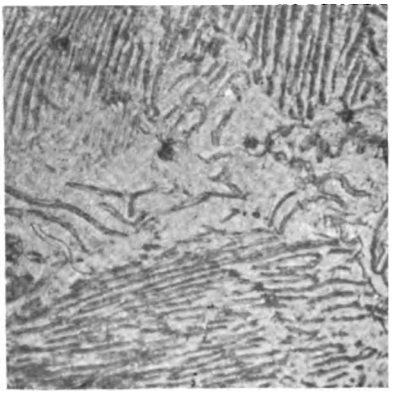
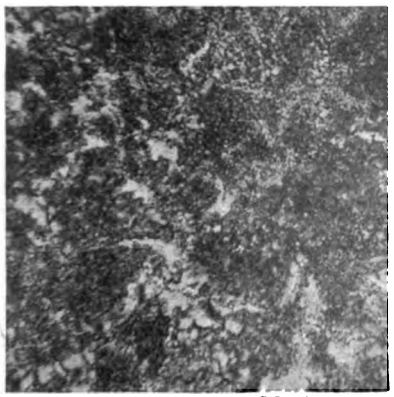
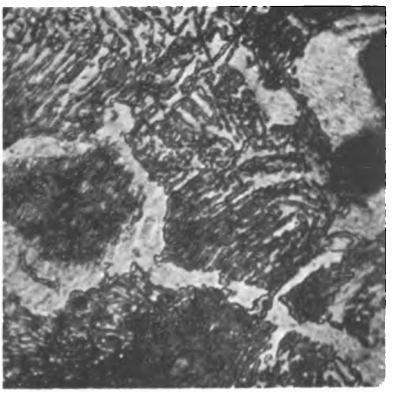


Fig. 39. × *140 diams.*

Fig. 40. × *850 diams.*

Brymbo No. 8. 0·927 C.





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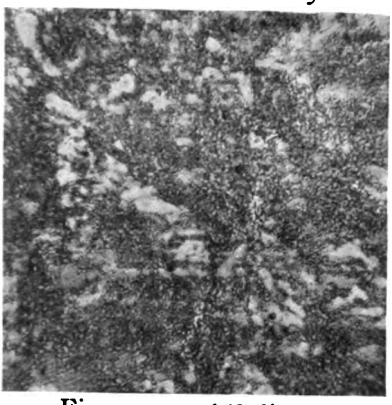
Slowly Cooled Steels.

Fig. 41. × *140 diams.* Fig. 42. × *850 diams.*

Brymbo No. 7. 1·161 C.



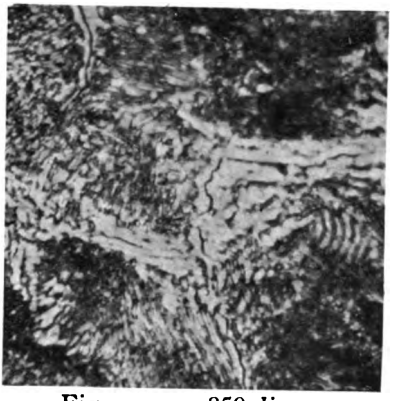
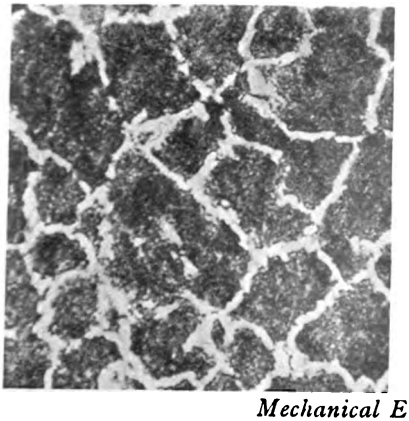


Fig. 43. × *140 diams.* Fig. 44. × *850 diams.*

Brymbo No. 5. 1·461 C.

Fig. 45. × *140 diams.* Fig. 46. × *850 diams.*

Brymbo No. 1. 1·800 C.



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Cast-Iron Slowly Cooled. × *850 diams.*

Fig. 47. *White Iron.*
Combined C. = 2·573%.
Graphitic C. = 0·190%.

Fig. 48. *Grey Iron.*
Combined C. = 1·124%.
Graphitic C. = 2·640%.

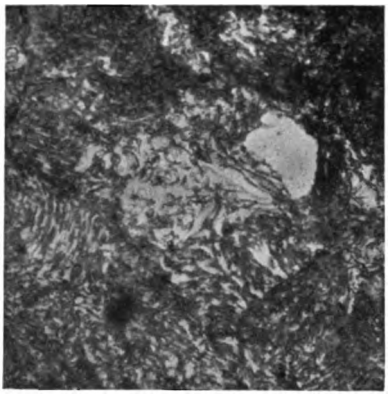


Fig. 49. *Total C. about 4·02%.*

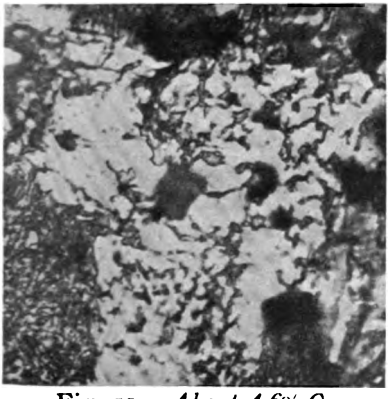
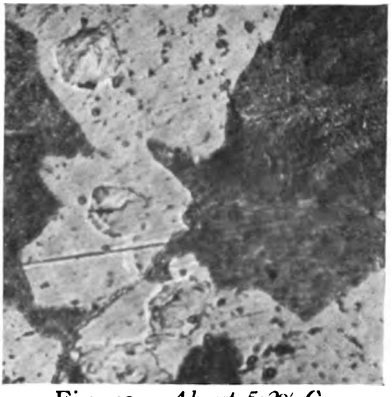


Fig. 50. *About 4·3% C.*

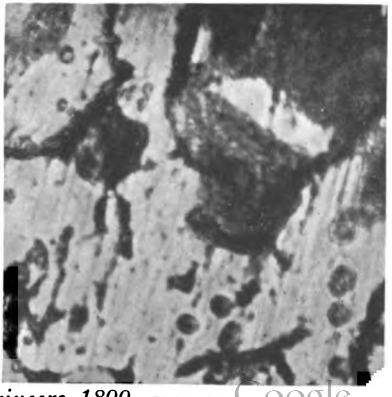
Grey Iron prepared in Electric Furnace.

Fig. 51. *About 4·6% C.*

Fig. 52. *About 5·2% C.*



Grey Iron prepared in Electric Furnace.



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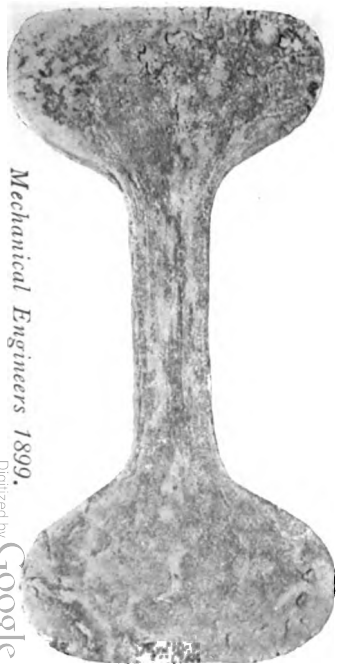
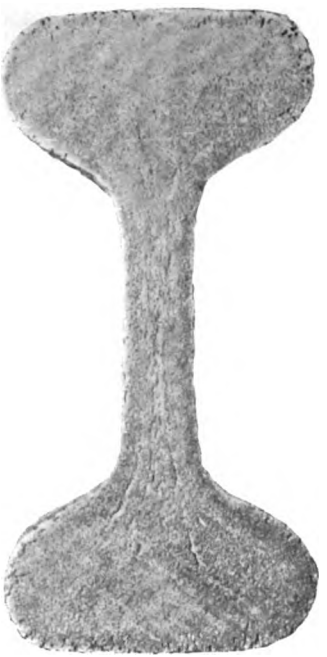
Rail Sections etched with warm dilute Sulphuric Acid.

Fig. 53. *Good Rail.* *0·54 C. 0·50 Mn. 0·16 P.*



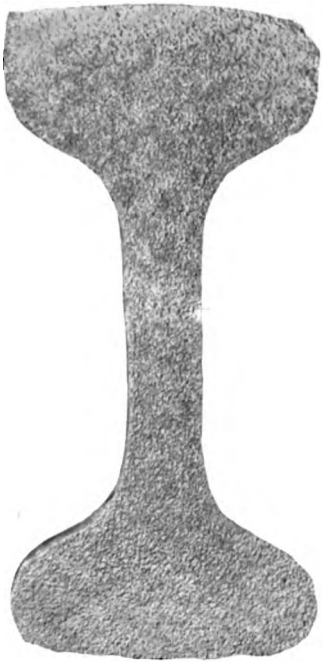
Rail 1.

Fig. 54. *Good Rail.* *0·40 C. 0·50 Mn. 0·07 P.*



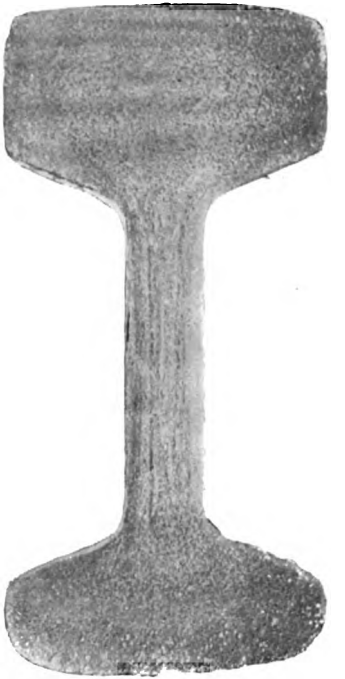
Rail 2.

Fig. 55. *Poor Rail.* *0·33 C. 0·70 Mn. 0·06 P.*



Rail 3.

Fig. 56. *High Manganese Rail.* *0·41 C. 0·90 Mn. 0·07 P.*



Rail 4.

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Plate 13.

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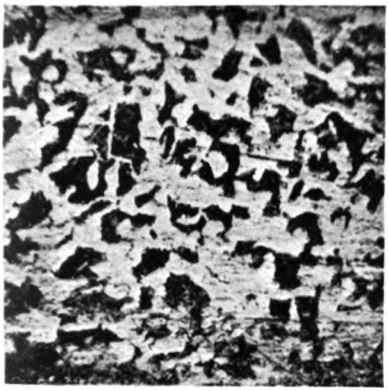
Rail Steel.

Rail 1, Plate 13. *Rail 2, Plate 13.*

Fig. 57. *Exterior of head* × *140 diams.* Fig. 58.



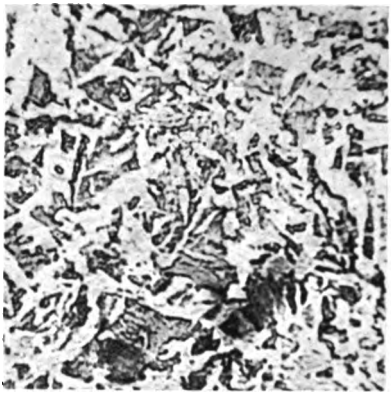


Fig. 59. *Interior of head* × *140 diams.* Fig. 60.

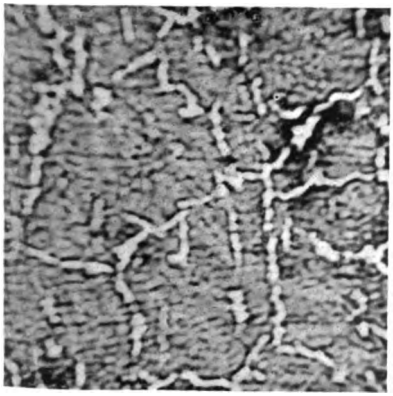
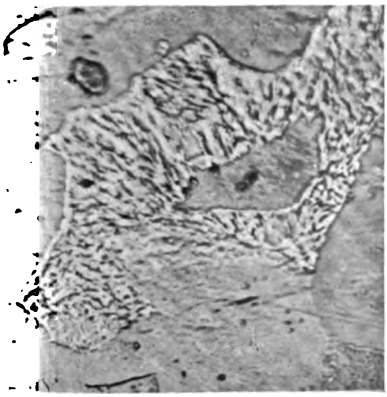
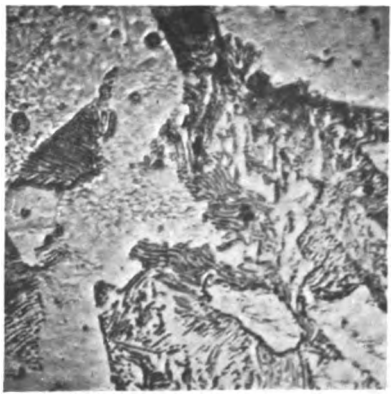


Fig. 61. *Pearlite of Rail* × *850 diams.* Fig. 62.





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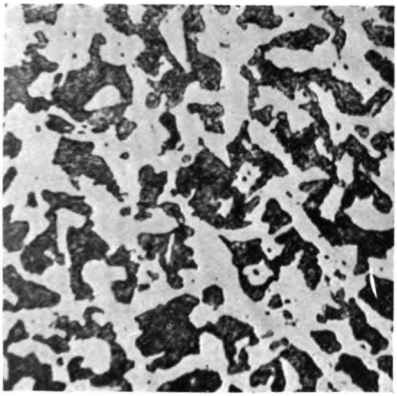
Rail Steel.

Rail 3, Plate 13. *Rail 4, Plate 13.*

Fig. 63. *Exterior of head × 140 diams.* Fig. 64.



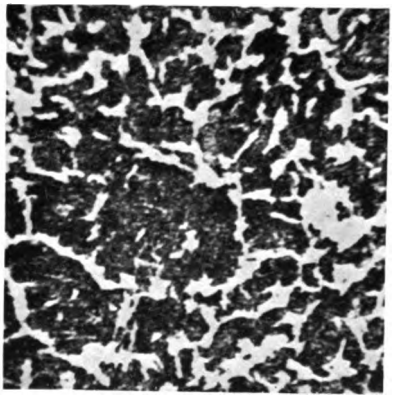
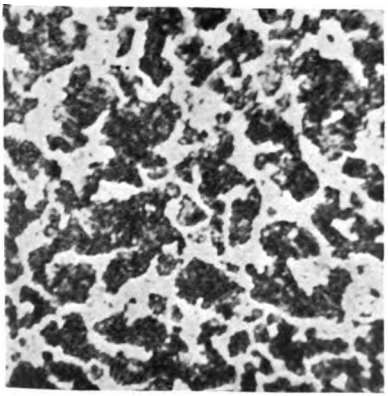


Fig. 65. *Interior of head × 140 diams.* Fig. 66.



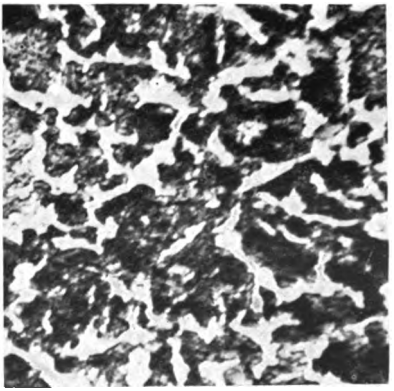
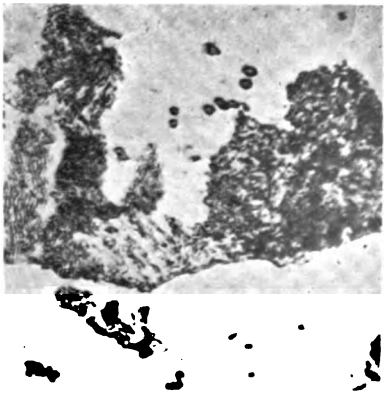


Fig. 67. *Pearlite of Rail × 850 diams.* Fig. 68.



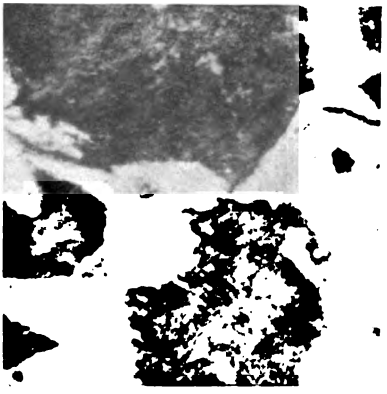


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Photo-Micrographs of different parts in a transverse section of a good Steel Rail. × *140 diams.*

Fig. 70.

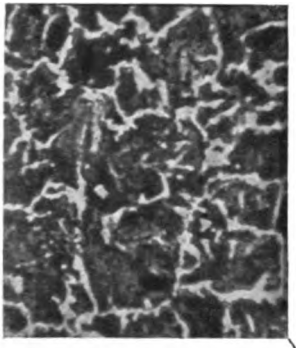

Fig. 71.

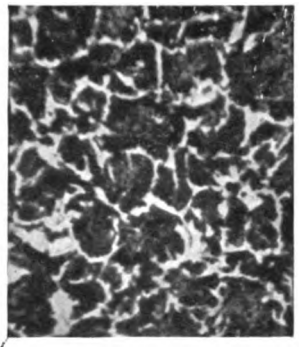

Fig. 69.

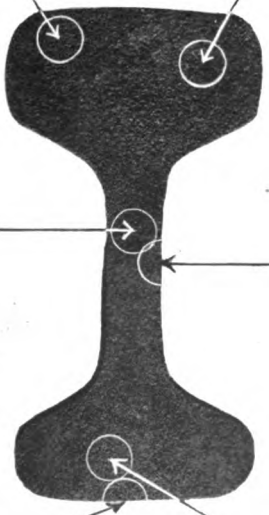

Fig. 72.

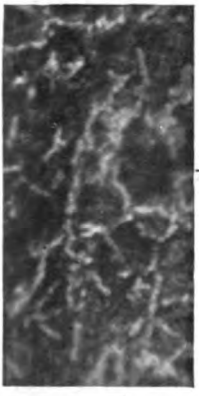

Fig. 73.

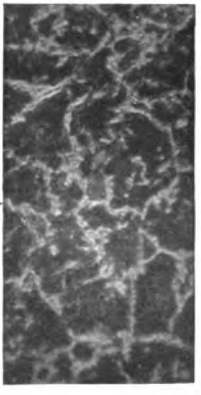

Fig. 74.

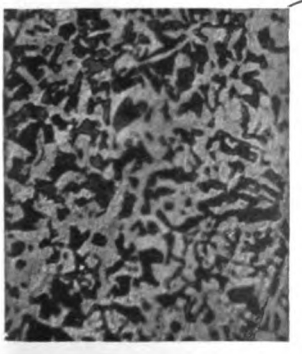

Fig. 75.

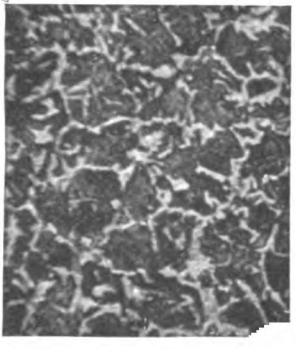

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Photo-Micrographs showing that corresponding parts of transverse sections of a rail have the same structures, although they are ten feet apart in the length of the rail.

Fig. 76. *End of Rail.*
Interior of head.
× *140 diams.*

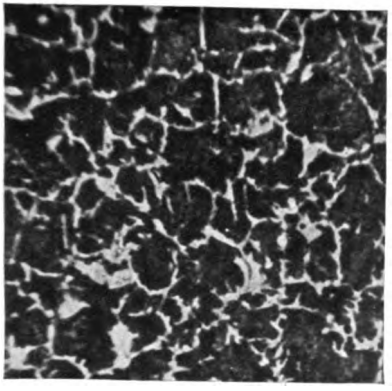


Fig. 77. *Middle of Rail.*
Interior of head.
× *140 diams.*

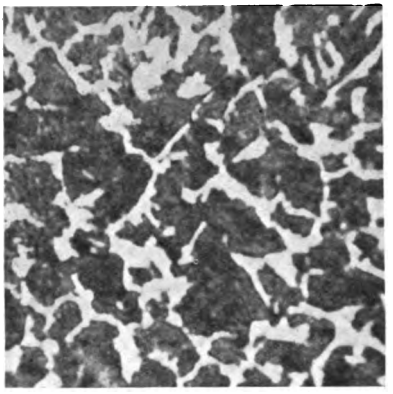


Fig. 78. *End of Rail.*
Interior of lower flange.
× *140 diams.*

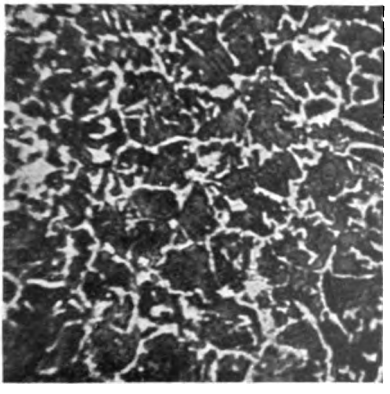
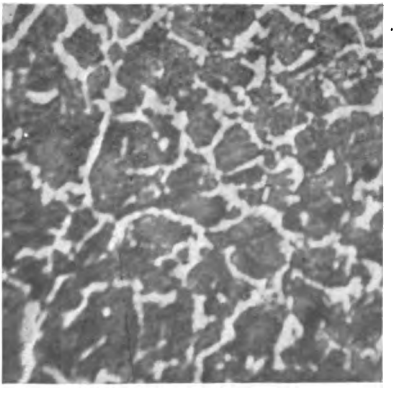


Fig. 79. *Middle of Rail.*
Interior of lower flange.
× *140 diams.*



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Low-Carbon Rail.

Showing the effect of varying the Thermal treatment of the Steel.
× 850 diameters.

Fig. 80.
Rolled Rail.

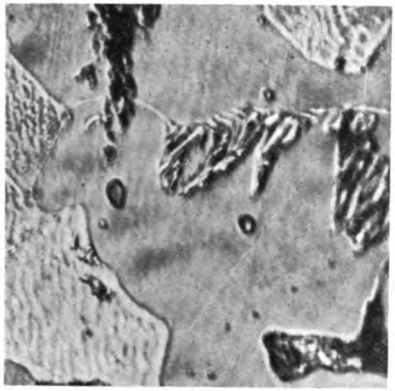


Fig. 81. *Annealed for 18 hours, at about 500° C. or 930° F.*

Fig. 82. *Troostite and Martensite. Quenched at 750° C. or 1,380° F.*

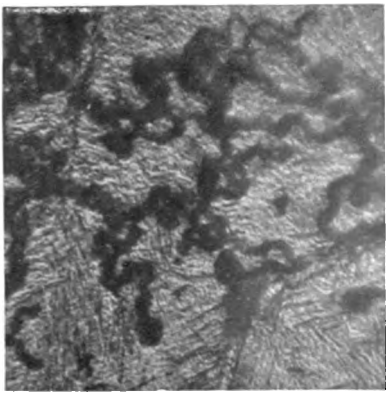
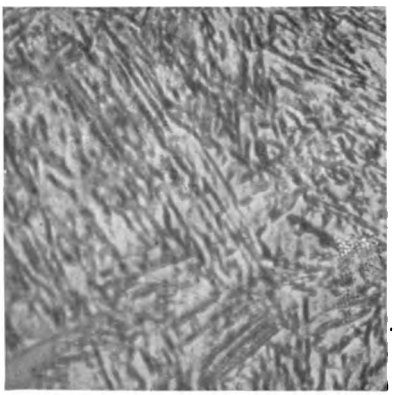


Fig. 83. *Martensite. Quenched above 1,000° C. or 1,830° F.*



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Die Steel, containing 0·82% Carbon.
Showing the effect of varying the Thermal treatment of the Steel.
× 850 diameters.

Fig. 84. *Forged and Slowly Cooled.*

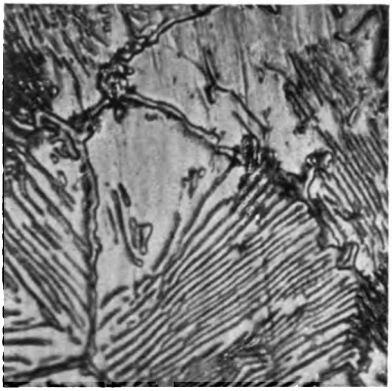


Fig. 85. *Annealed after Forging.*

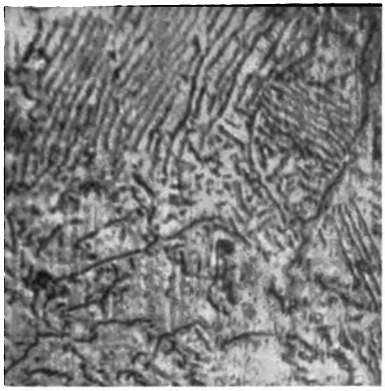


Fig. 86. *Quenched in Water at about 1,000° C. or 1,830° F.*

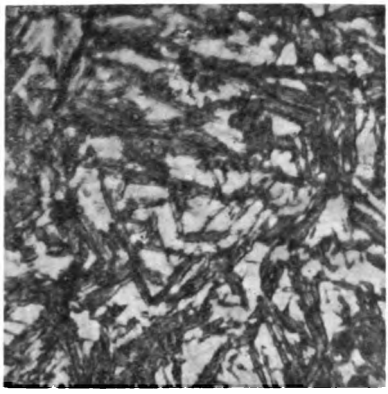


Fig. 87. *Tempered to Straw Color, about 243° C. or 470° F.*

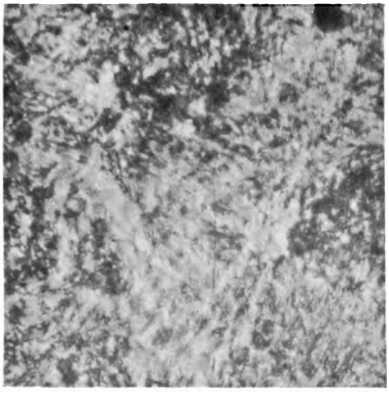


Fig. 88. *Quenched at 750° C. or 1,380° F. Troostite, Martensite, and Ferrite.*

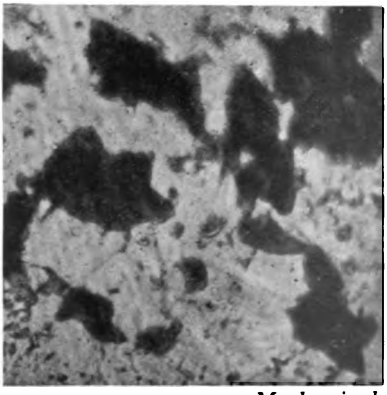
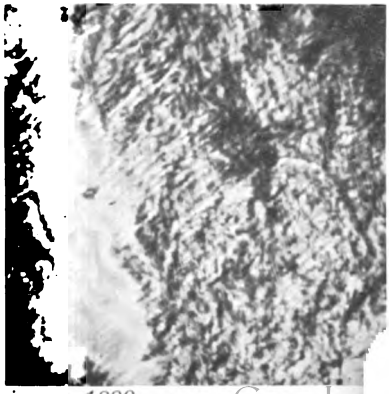


Fig. 89. *Burnt. Heated to over 1,100° C. or 2,000° F. Graphite visible.*



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Chrome Steel, magnified 850 diameters.

Fig. 90. *Soft.* *Tire and Axle Steel. 0·32 Cr. 0·44 C.* Fig. 91. *Hard.*

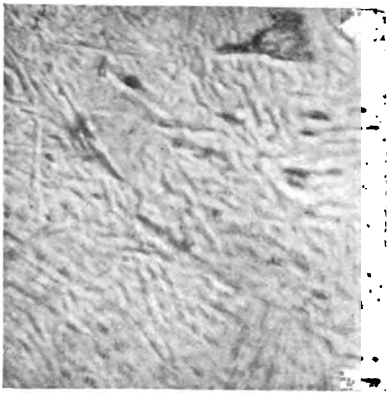
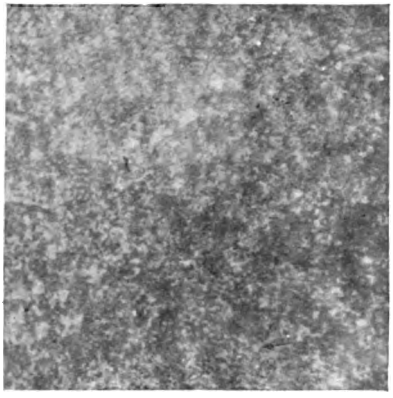


Fig. 92. *Soft.* *Tool Steel 0·46 Cr. 0·85 C.* Fig. 93. *Hard.*



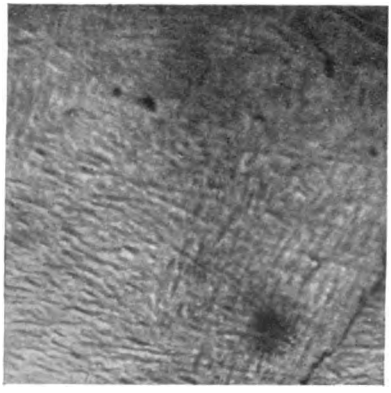
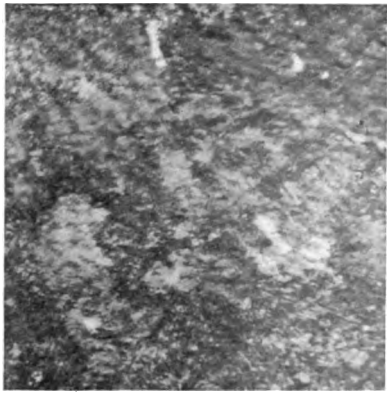


Fig. 94. *Soft.* *Spring Steel. 0·17 Cr. 0·78 C.* Fig. 95. *Hard.*



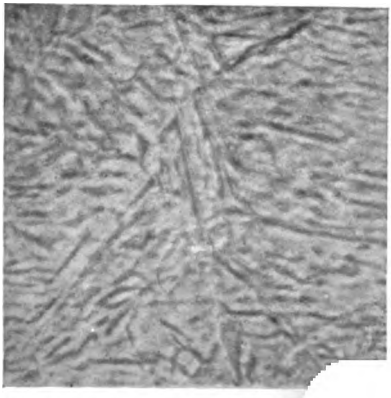


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Photo-Micrographs of Steel and Iron.

Fig. 96. *Soft Swedish Steel.*
0·04% Carbon × 50 diams.

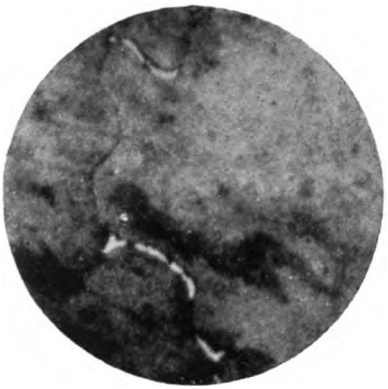

Fig. 97. *Martensite structure in soft steel.*
0·15% Carbon × 50 diams.

Fig. 98. *Steel cooled in slag.*
0·27% Carbon × 200 diams.

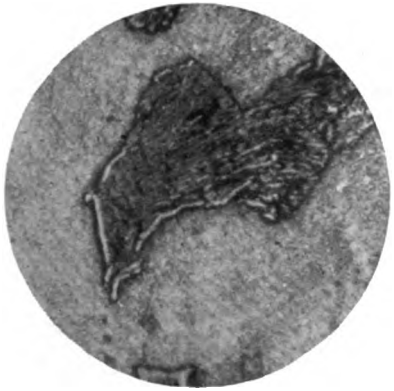

Fig. 99. *Tool Steel cooled in slag.*
1·38% Carbon × 30 diams.

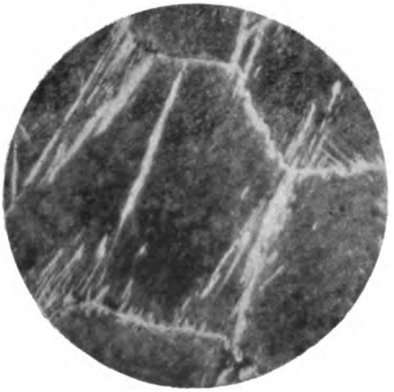

Fig. 100. *Brittle Casting meshed with Sulphide of Manganese.*

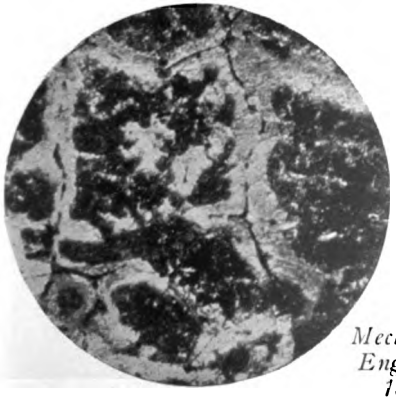

Fig. 101. *Steel Rail Head, longitudinal section × 130 diams.*

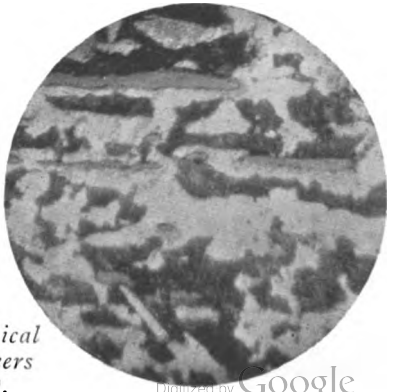

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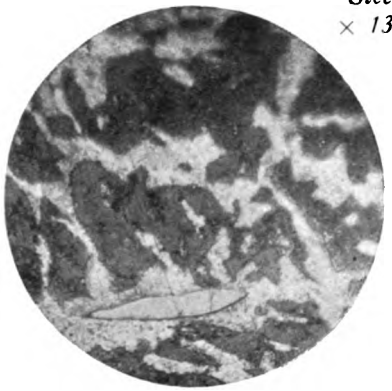
Photo-Micrographs of Steel and Iron.

Fig. 102. *Before crushing.* *Steel Shaft, × 130 diams.* Fig. 103. *After crushing.*



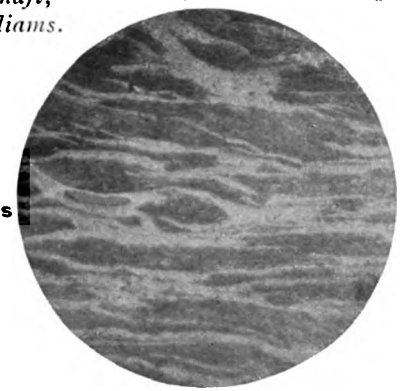
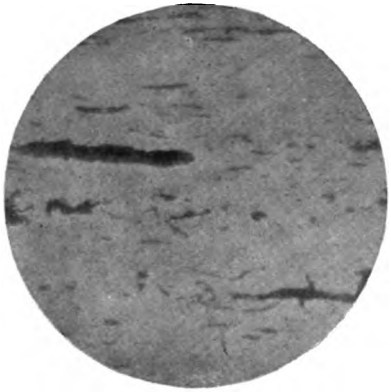


Fig. 104. *Wrought-Iron Shaft, longitudinal section × 50 diams.*

Fig. 107. *Surface of worn Locomotive Tire × 50 diams.*



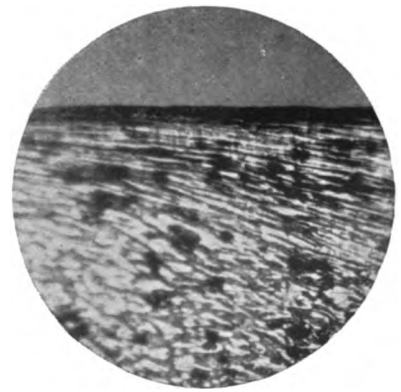


Fig. 105. *Natural size. Surface of Head.*

Fig. 106. *× 10 diams. Longitudinal vertical section.*

St. Neot's Steel Rail.

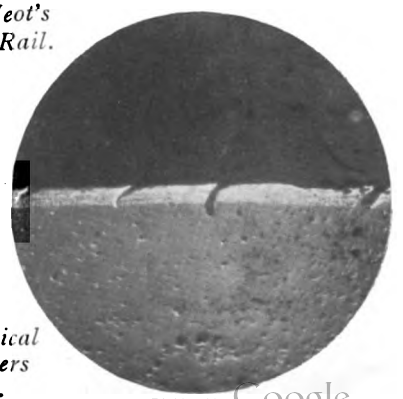


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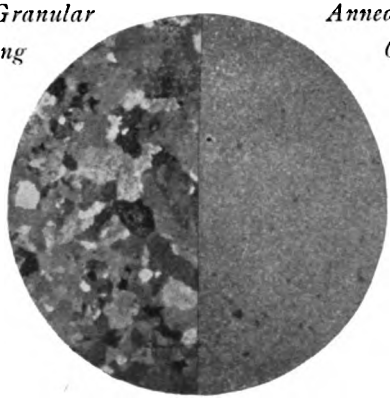
Fig. 108. *Coarsely Granular Annealed Soft Steel, containing 0·12% Carbon.*

Before heating to just above Ar3.



After heating to just above Ar3.

Fig. 109. *Iron and Carbon, cooled rapidly.*

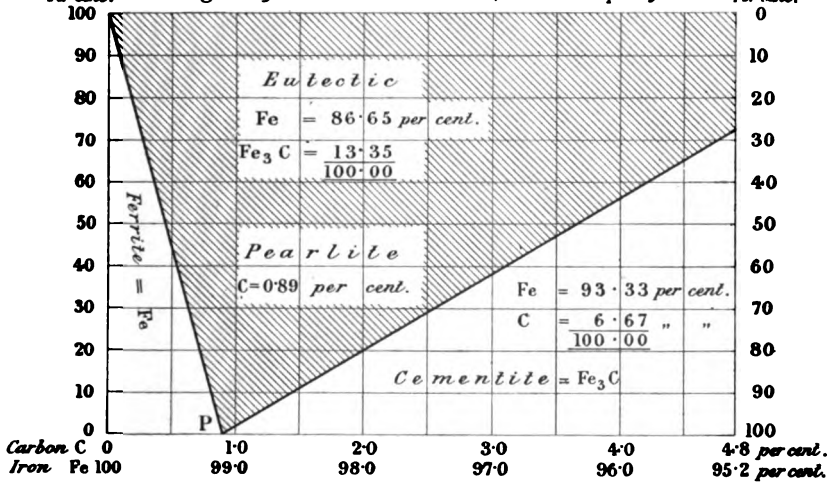
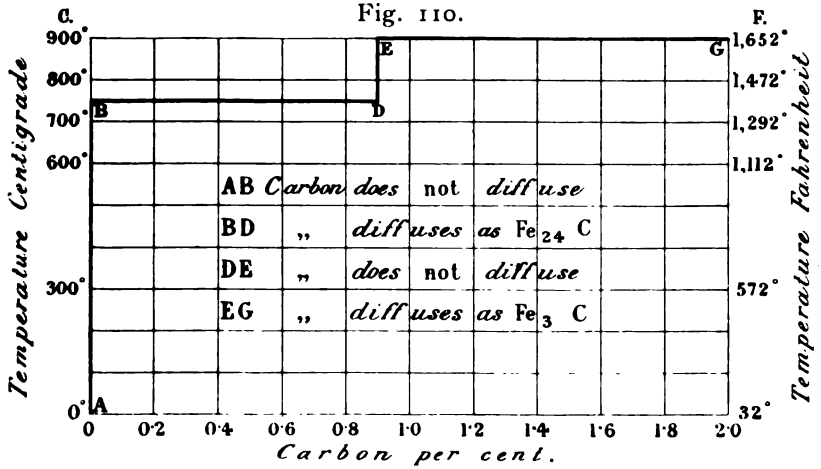

Per cent.
Per cent.
Eutectic
Fe = 86·65 per cent.
Fe3 C = 13·35 / 100·00
Ferrite = Fe
Pearlite
C=0·89 per cent.
Fe = 93·33 per cent.
C = 6·67 / 100·00 " "
Cementite = Fe3C
P
Carbon C 0 1·0 2·0 3·0 4·0 4·8 per cent.
Iron Fe 100 99·0 98·0 97·0 96·0 95·2 per cent.

Fig. 110.



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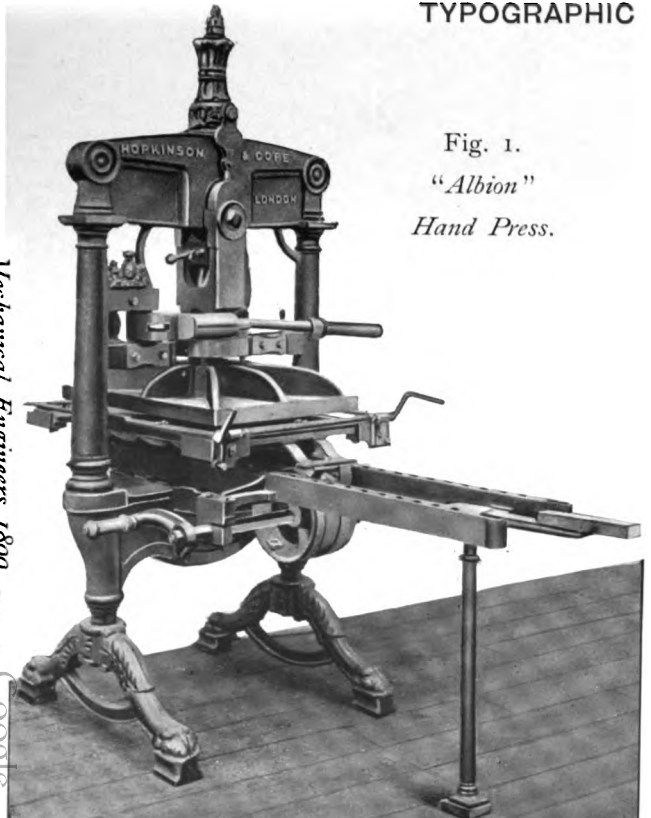

Fig. 1.
"Albion"
Hand Press.

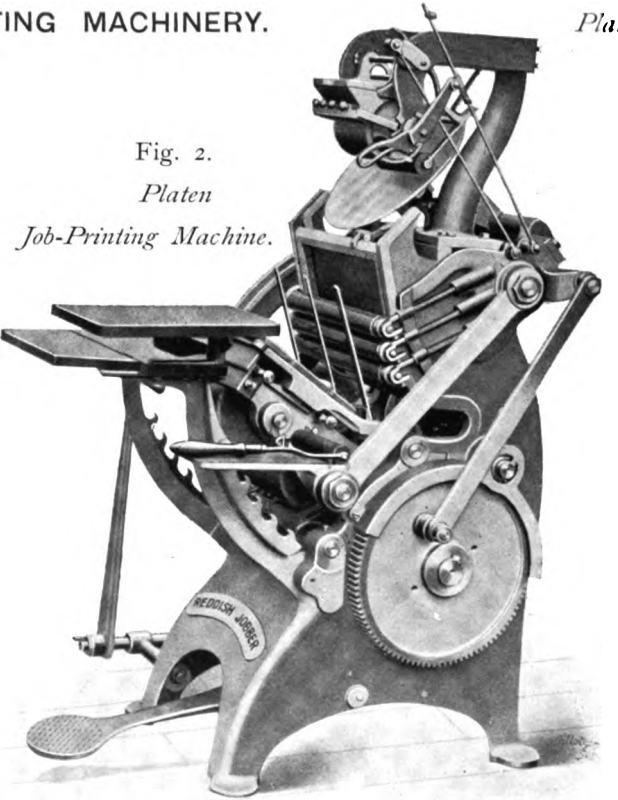

Fig. 2.
Platen
Job-Printing Machine.

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Plate 24.

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"Albion" Hand Press.

Fig. 3.

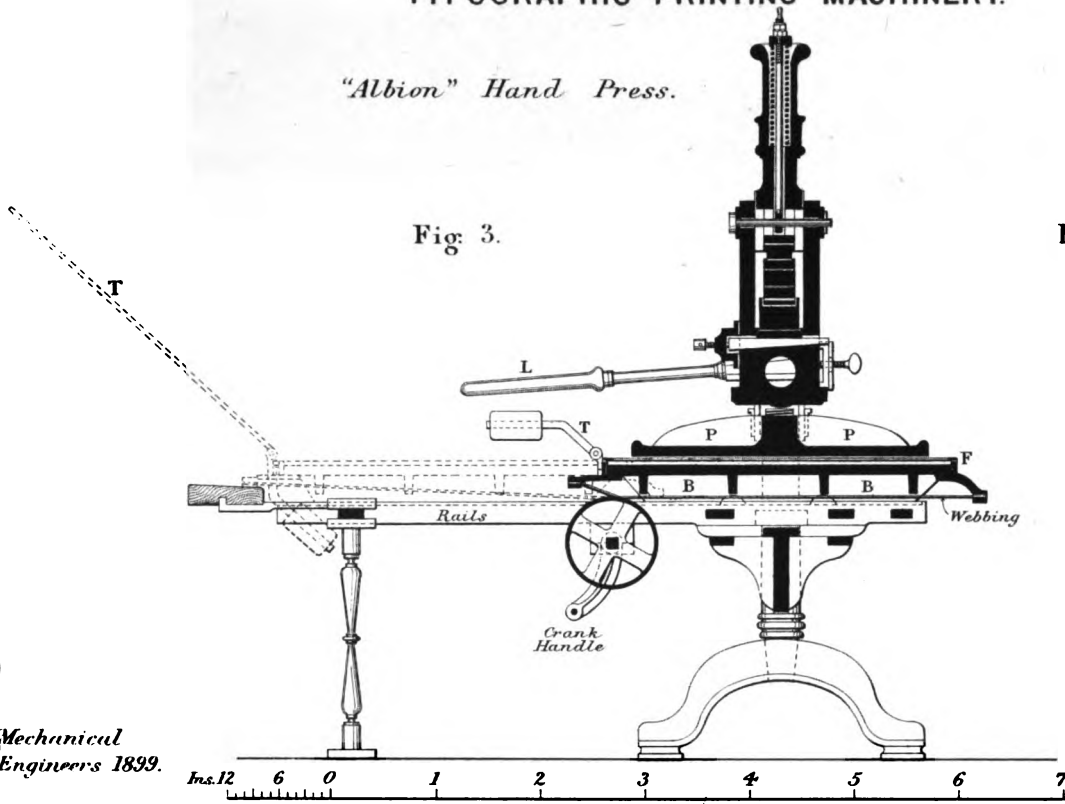
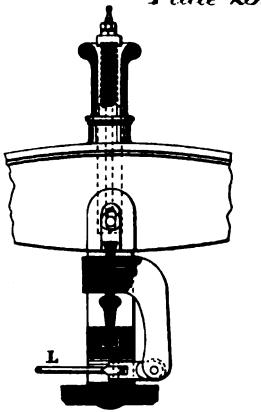


Fig. 4.



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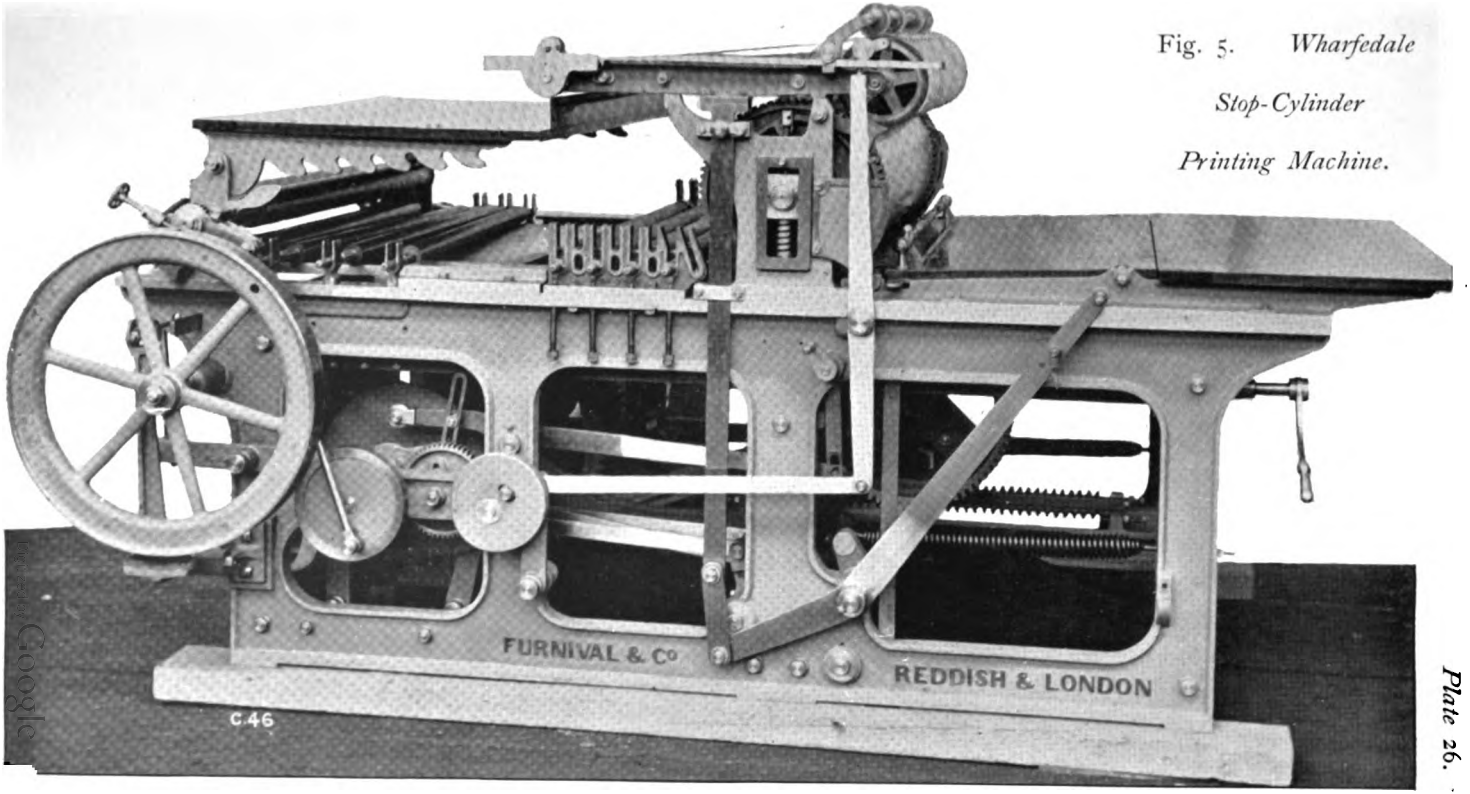

Fig. 5. *Wharfedale Stop-Cylinder Printing Machine.*

Plate 26.

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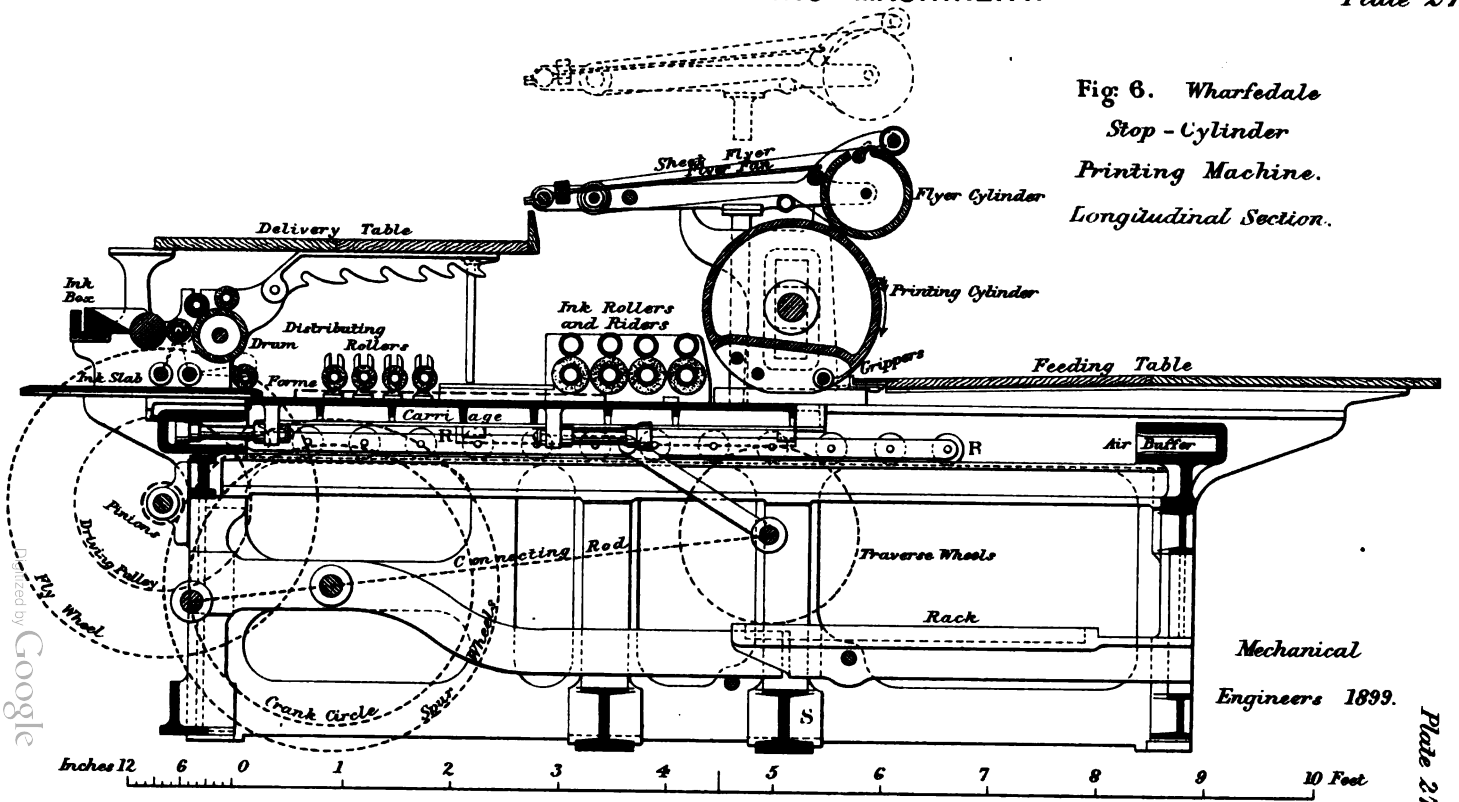

Fig: 6. *Wharfedale Stop-Cylinder Printing Machine. Longitudinal Section.*

Mechanical Engineers 1899.

Plate 27.

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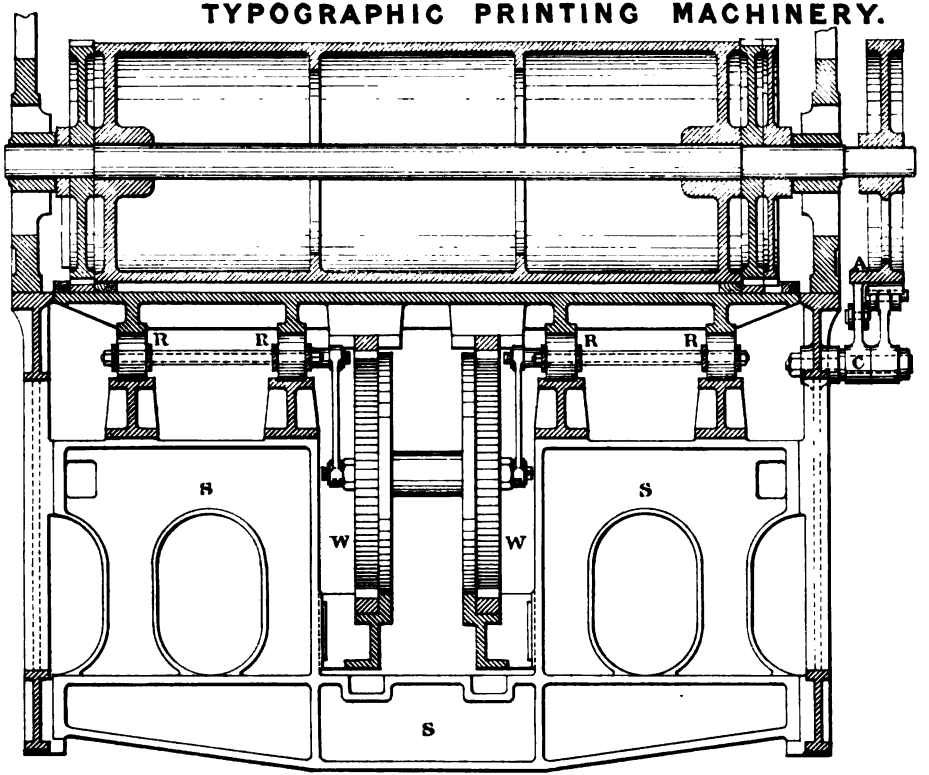

Fig. 7.
Wharfedale Stop-Cylinder Printing Machine. Cross Section.

Scale 1/16th.

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Wharfedale Stop-Cylinder Printing Machine.

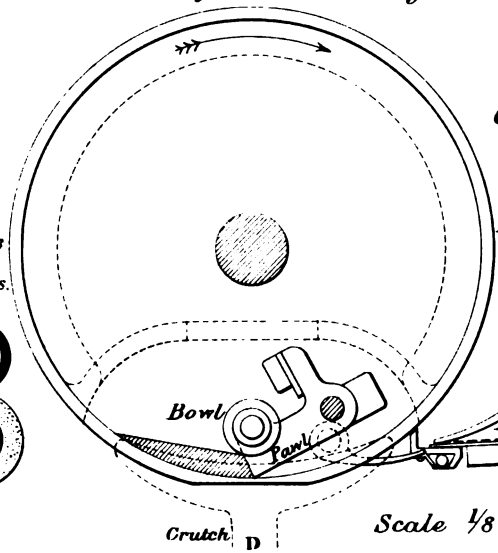


Fig. 8.
Cylinder Check.

Loose wheel removed.

Inking Rollers and Steel Tube Riders.

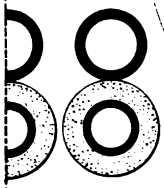
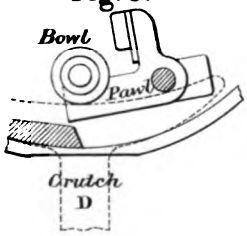


Fig. 9.



Crutch D

Scale 1/8th

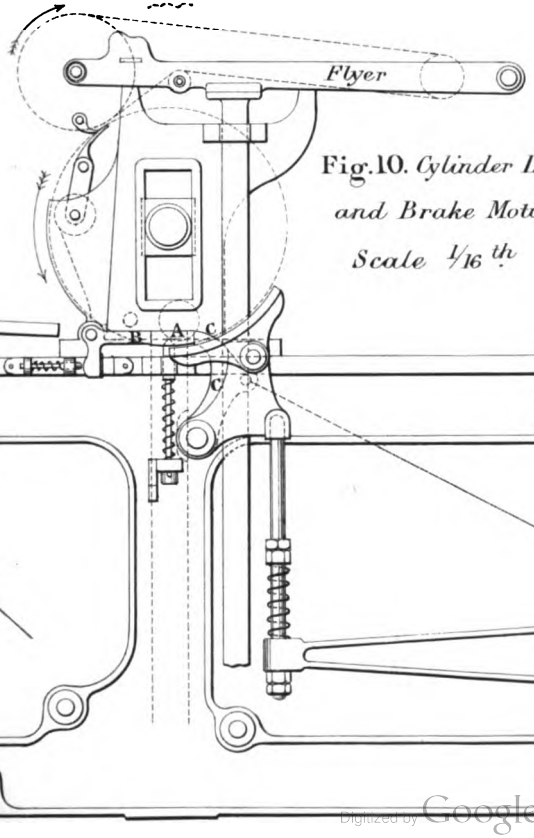


Fig. 10. *Cylinder Lock and Brake Motion.*
Scale 1/16th

Fig. 11.

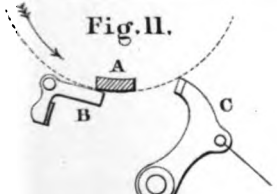


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Fig. 12. *Fine-Art Stop-Cylinder Printing Machine.*

In working position.

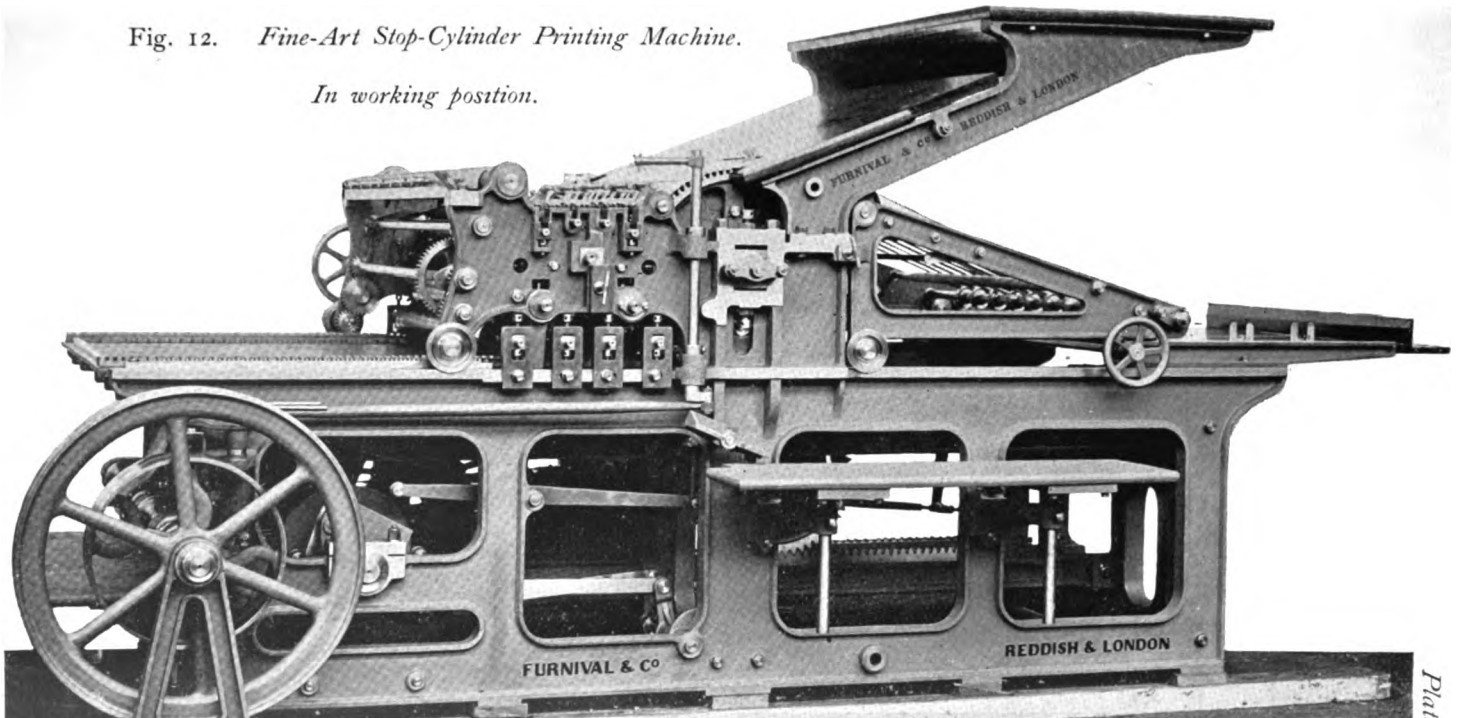

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Fig. 13. *Fine-Art Stop-Cylinder Printing Machine.*

In cleaning position.

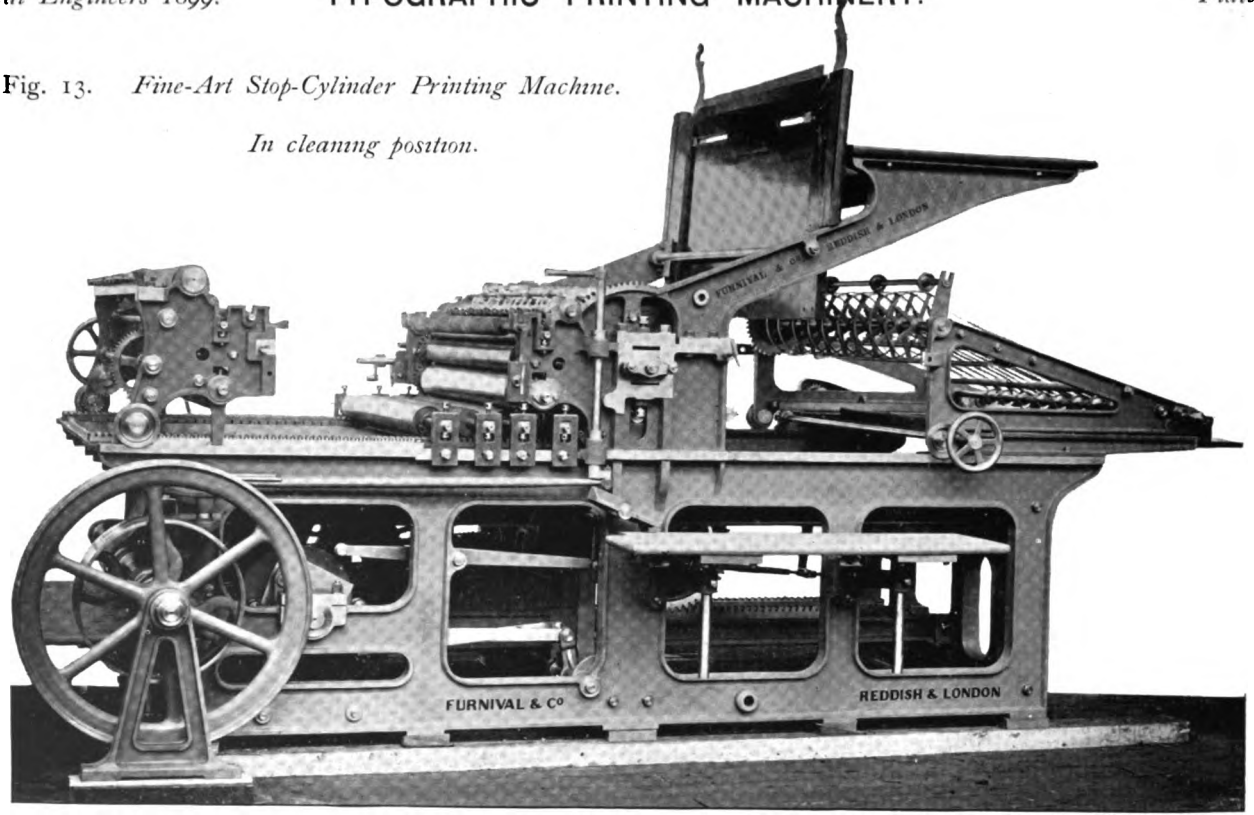

Plate 31.

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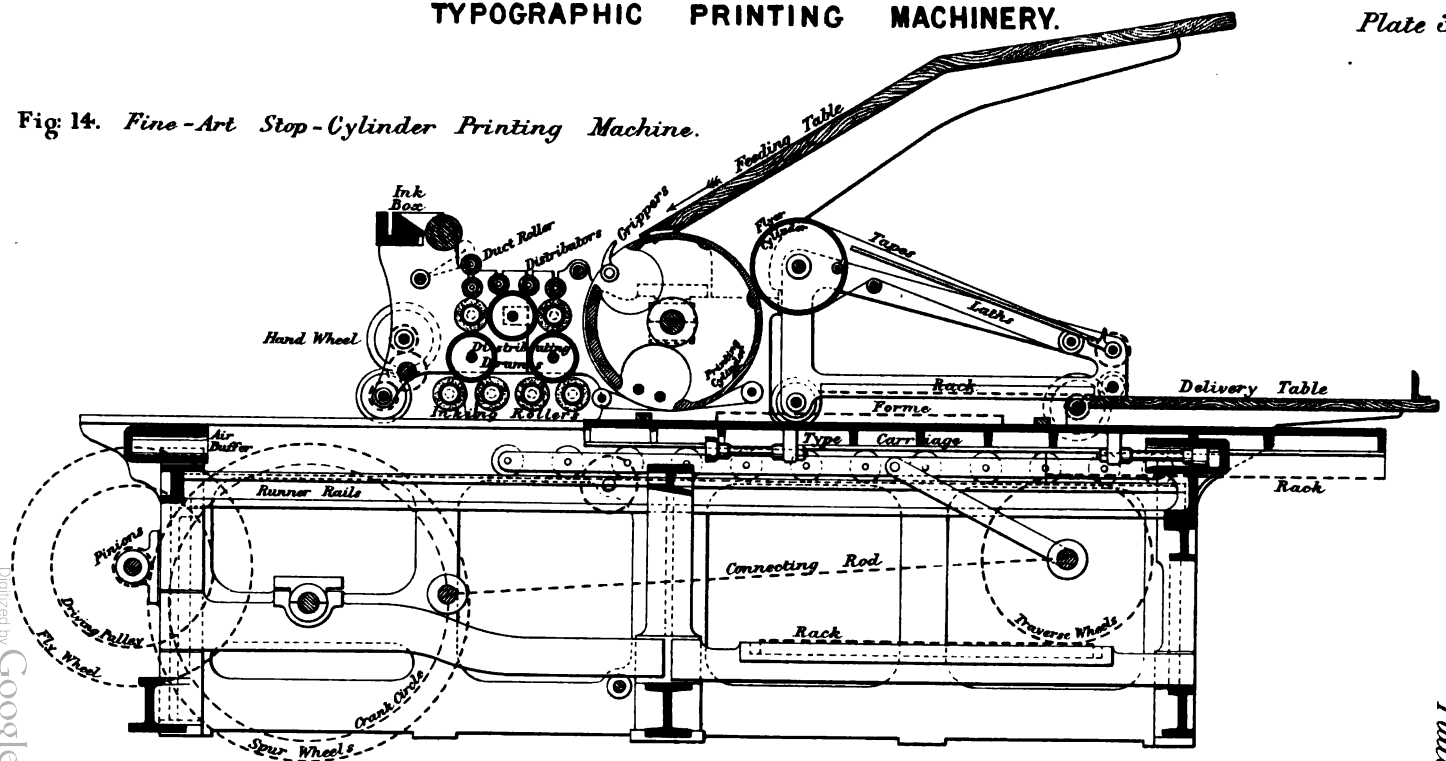
Fig. 14. *Fine-Art Stop-Cylinder Printing Machine.*



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Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Plate 32.

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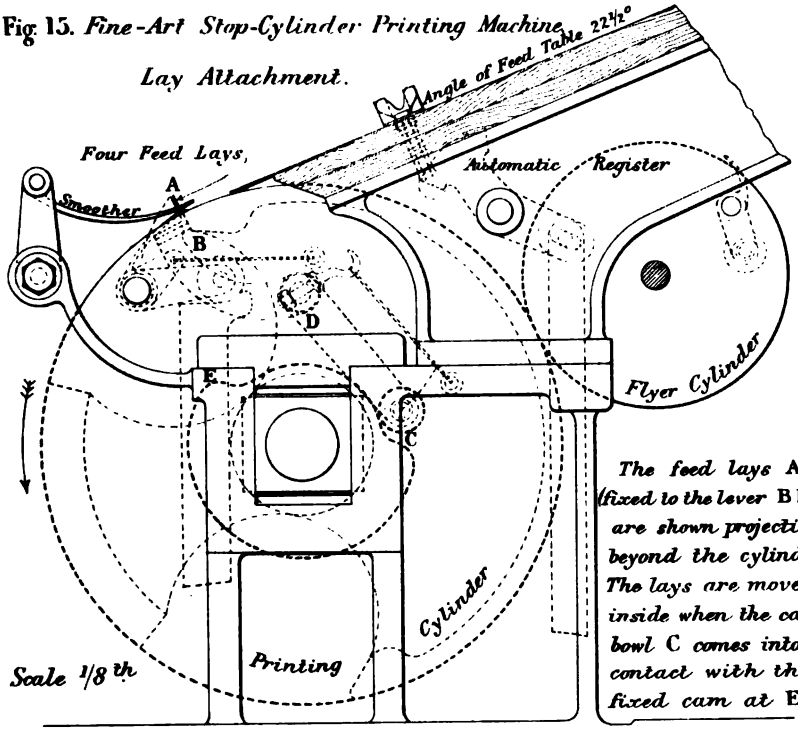
Fig. 15. *Fine-Art Stop-Cylinder Printing Machine.*

Lay Attachment.



The feed lays A *(fixed to the lever* BDC*) are shown projecting beyond the cylinder. The lays are moved inside when the cam bowl* C *comes into contact with the fixed cam at* E.

Fig. 16. *Two-Revolution Single-Cylinder Printing Machine.*

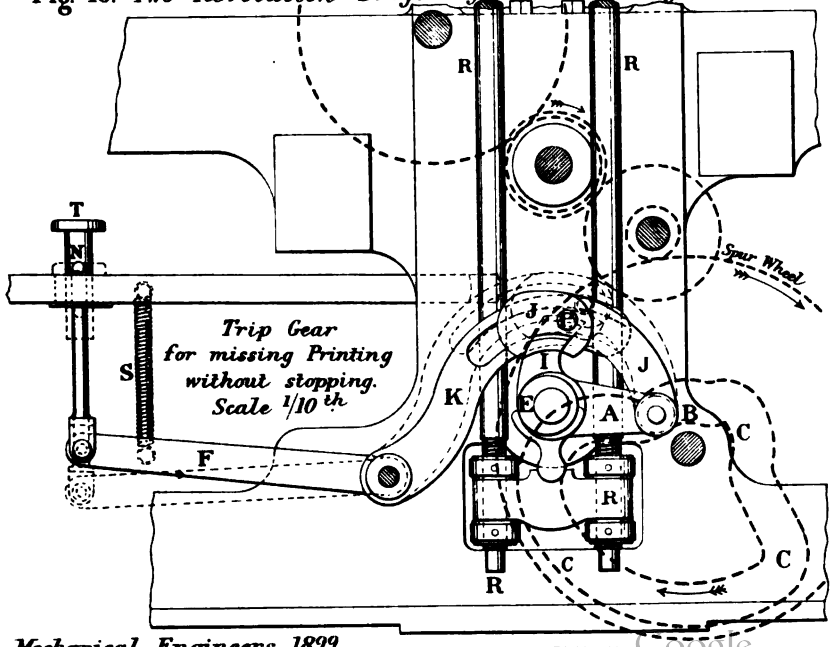


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Fig. 17. *Two-Revolution Single-Cylinder Printing Machine.*

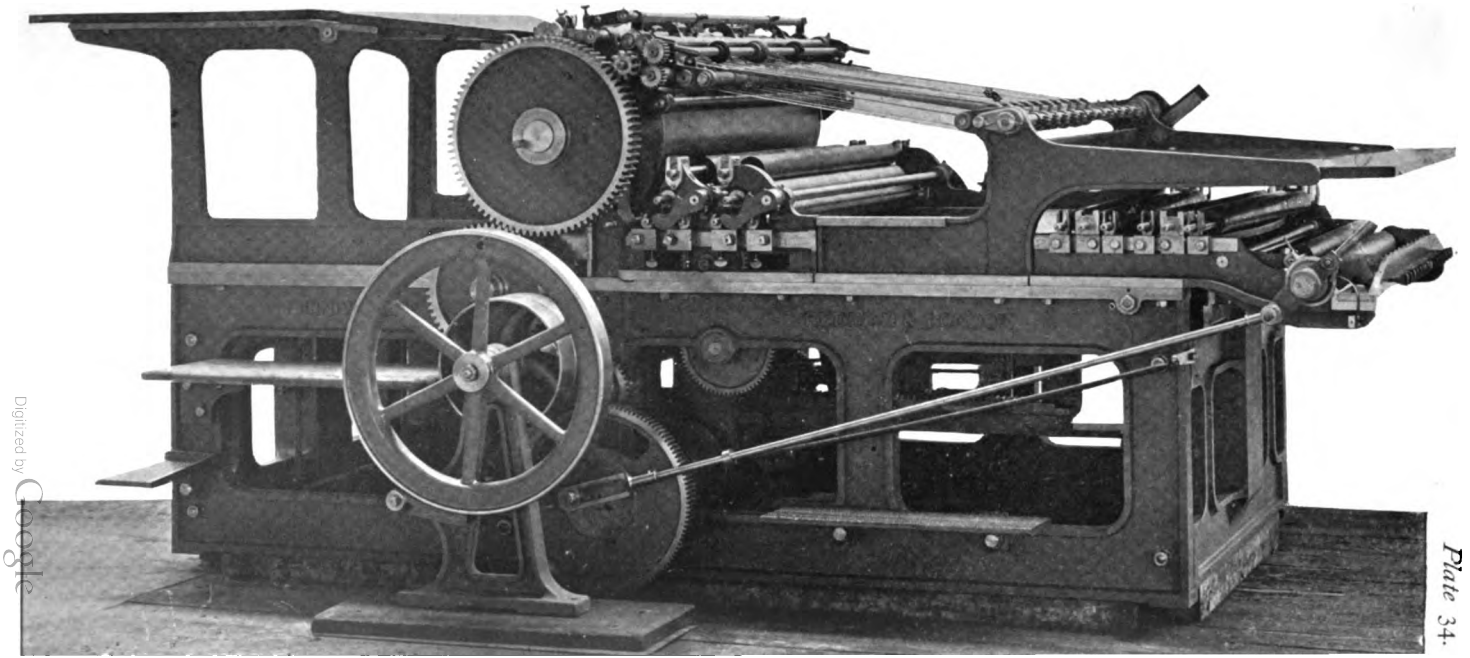

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Plate 34.

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Fig. 18. *Two-Revolution Single-Cylinder Printing Machine.*

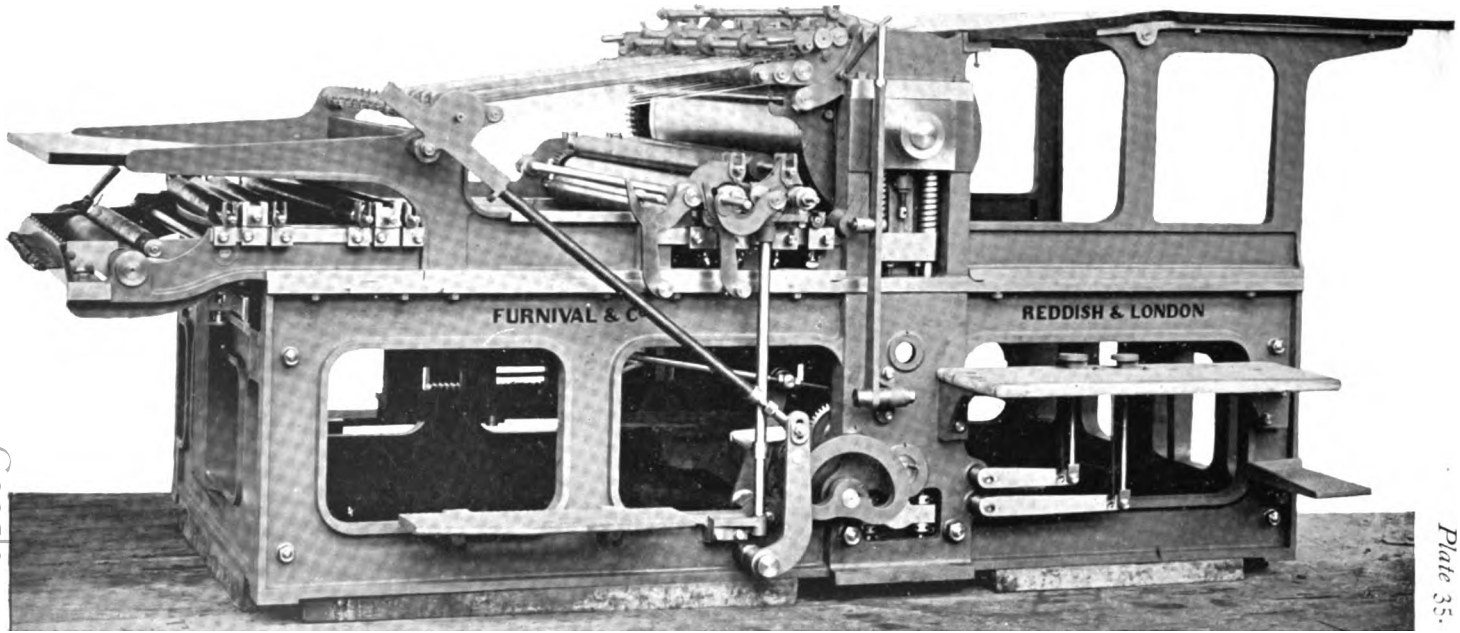

Plate 35.

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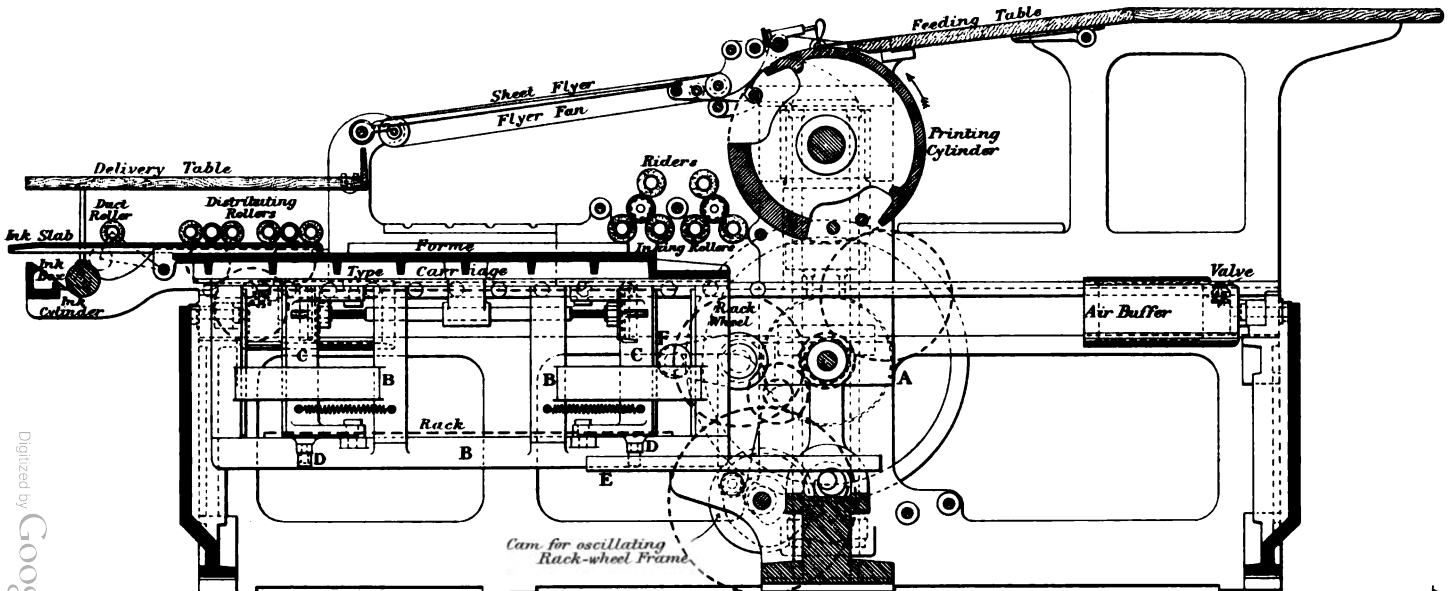
Fig. 19. *Two-Revolution Single-Cylinder Printing Machine.*



Mechanical Engineers 1899.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Plate 36.

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Fig. 20. *Wharfedale Two-Colour Printing Machine.*

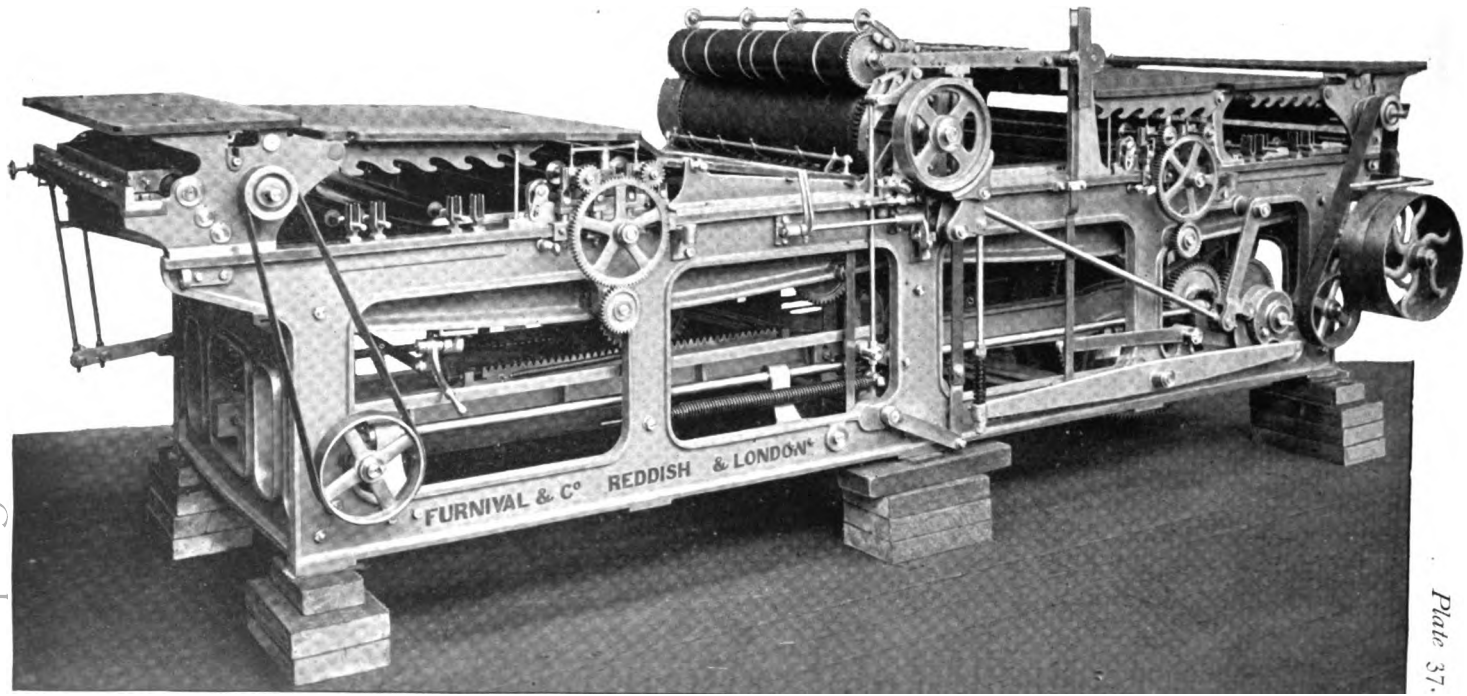

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Plate 37.

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Fig. 21. *Single-Revolution "Perfector" Printing Machine.*

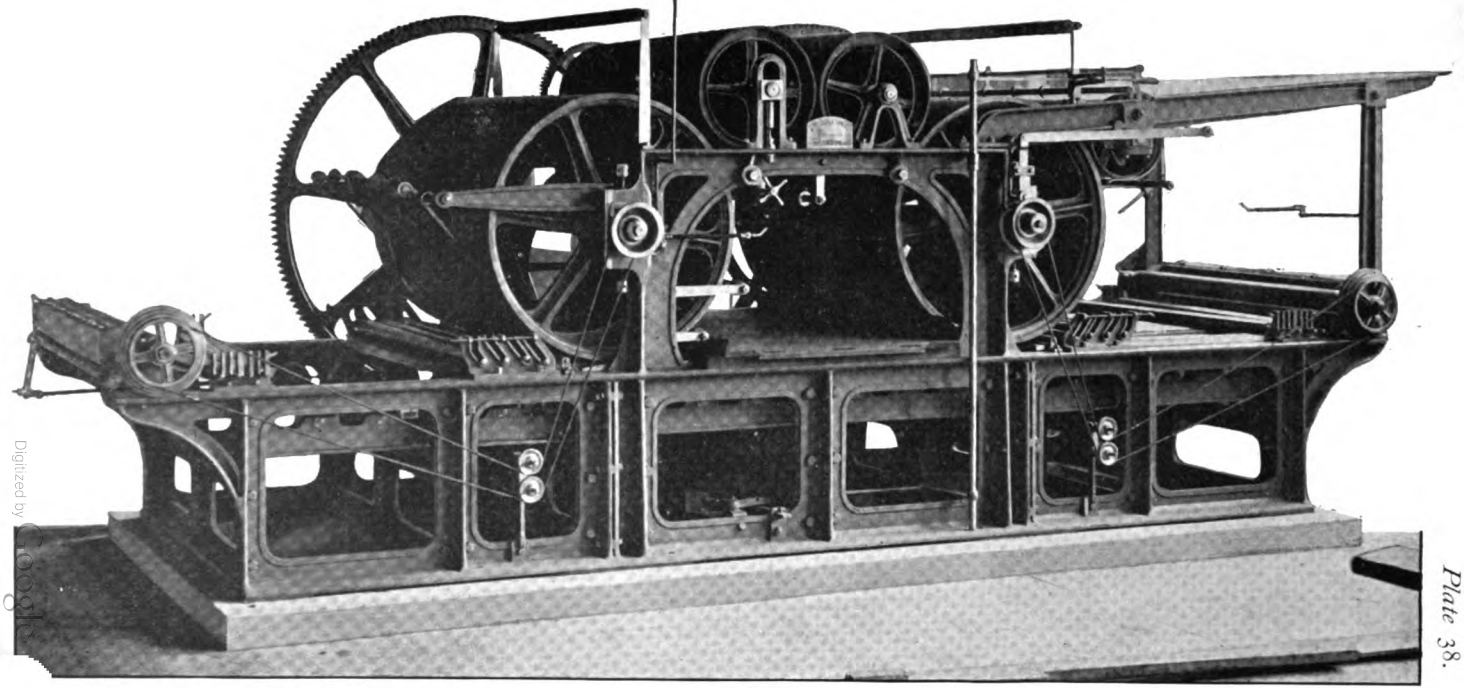

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Plate 38.

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Fig. 22. ***Single-Revolution "Perfector" Printing Machine.***

Printing both sides.

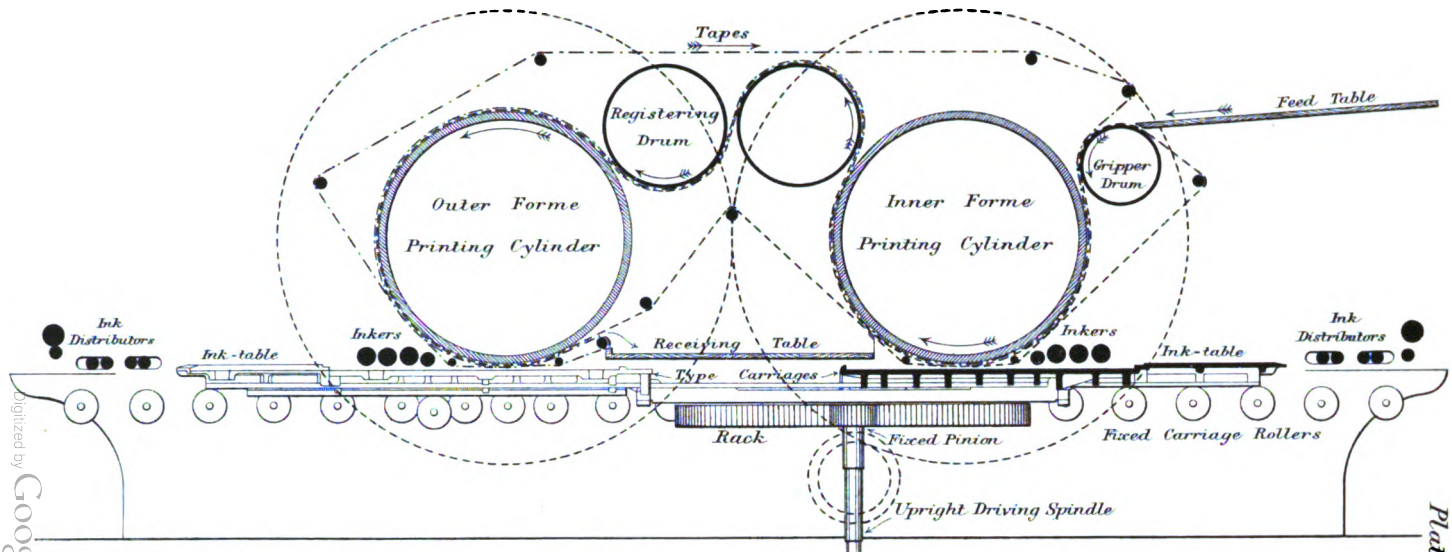

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Plate 39.

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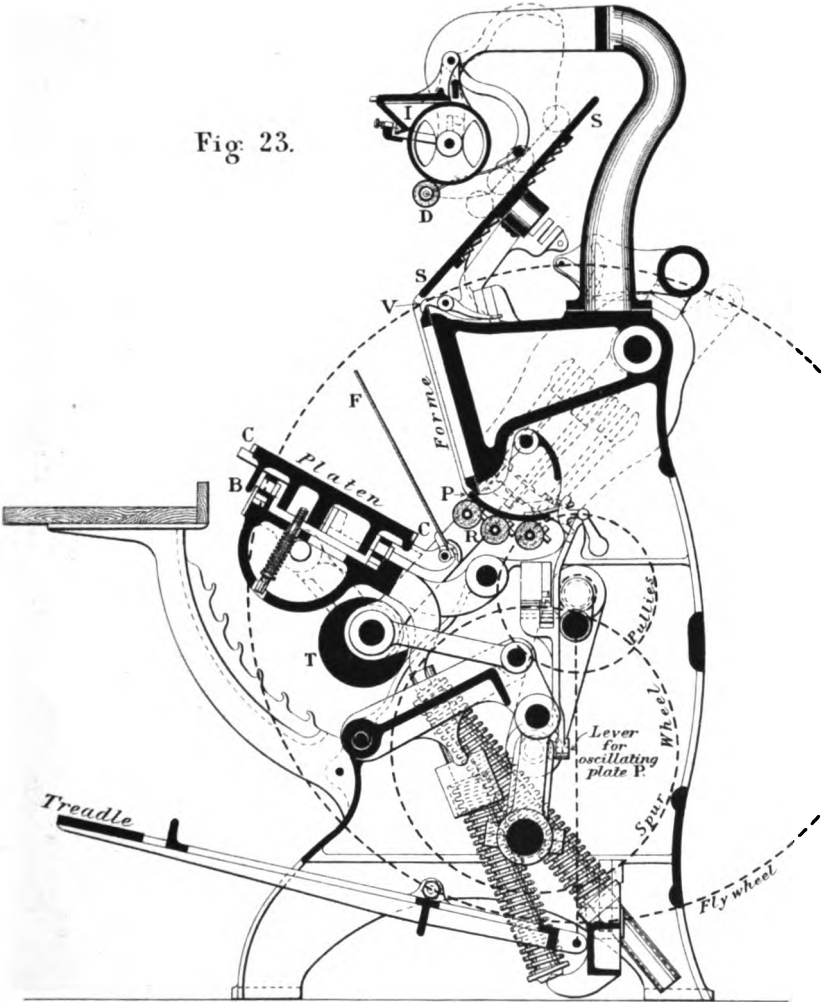
Platen Job-Printing Machine.

Fig. 23.



Front view of Platen showing arrangement of "Throw-off" and Impression Adjustment.

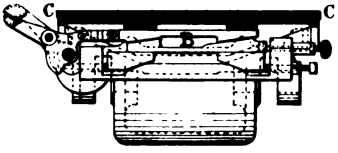


Fig. 24.

Mechanical Engineers 1899.

Inches 12 6 0 1 2 Feet

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EVAPORATIVE CONDENSERS.

Plate 41.

Details of Vertical Tubes.

Fig. 1. *Theisen.*

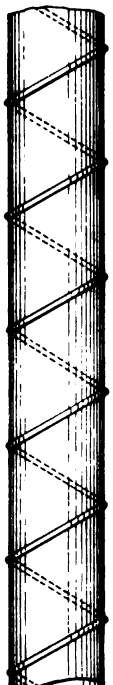


Fig. 2. *Wright.*

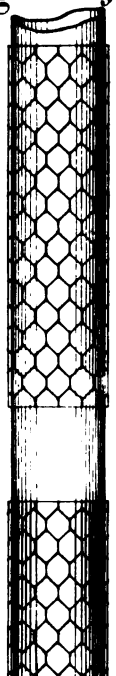


Fig. 3. *Fraser.*

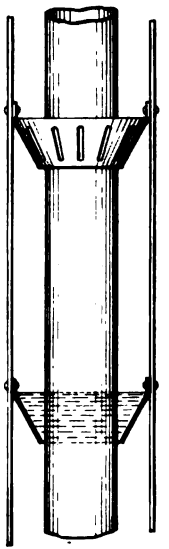


Fig. 4.

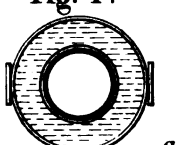


Fig. 5. *Corrugated Tube.*

Fig. 6.

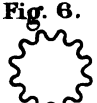
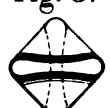


Fig. 7. *Row.*

Fig. 8.



Mechanical Engineers 1899.

Scale ¼th.

Plate 41.

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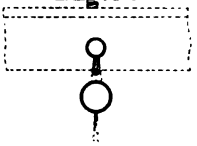
Distribution of Water over Tubes.

Fraser Horizontal. Tank with Perforated Pipe.

Fig. 9.

Fig. 10.



Horizontal. Tank with Slotted Pipe.

Fig. 11.

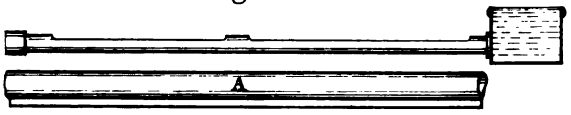
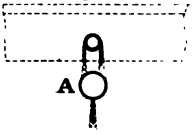


Fig. 12.



Enlarged views of wrought-iron Tube A.

Fig. 13.

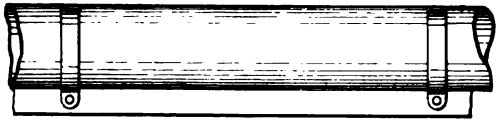


Fig. 14.

Fig. 15.

Spiral Distributor

Ledward Perforated Pipe with Corrugated c.i. Tube.

Fig. 16.

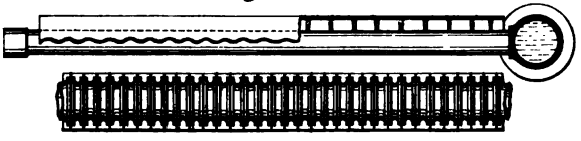


Fig. 17.

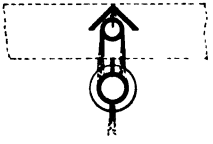


Fig. 18.

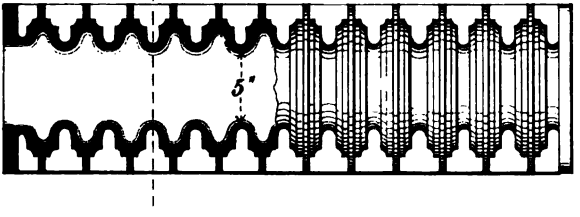
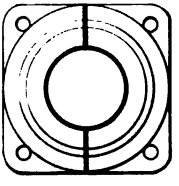


Fig. 19.



Mechanical Engineers 1899.

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Distribution of Water over Tubes.

Wooden – Trough Distributor.

Fig. 20.

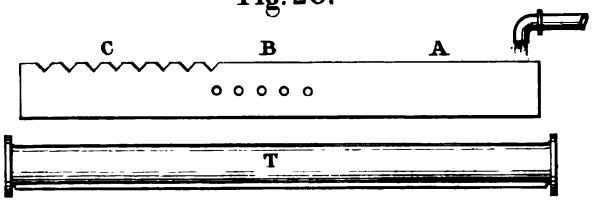
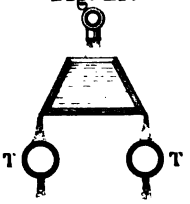


Fig. 21.



Enlarged views of cast-iron Tube T

Fig. 22.

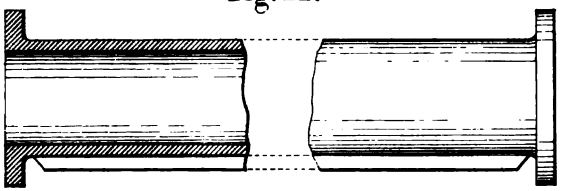
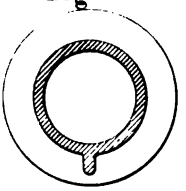


Fig. 23.



V *Notch Trough.*

Fig. 24.

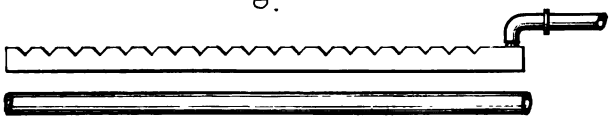


Fig. 25.

V *Perforated Trough.*

Fig. 26.

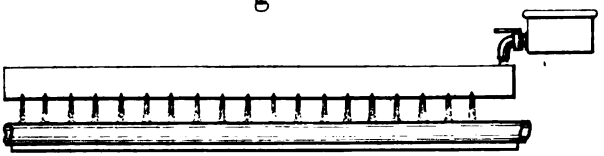
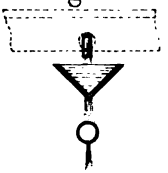


Fig. 27.



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EVAPORATIVE CONDENSERS.

Fig. 28. *Fraser*

Vertical Brass Tubes.

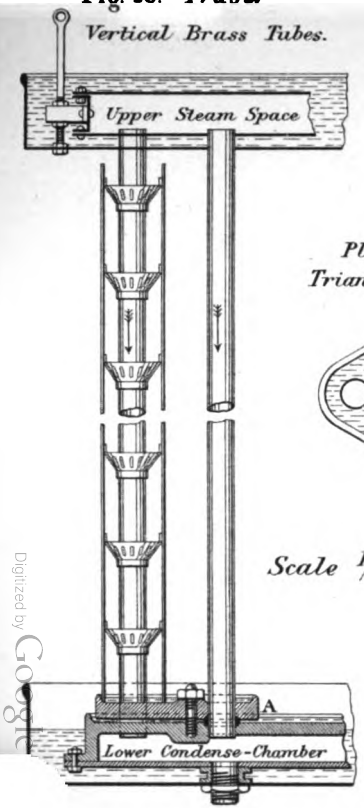
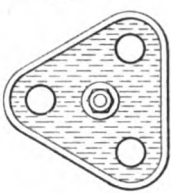


Fig. 29.
Plan of A.
Triangular Plate.

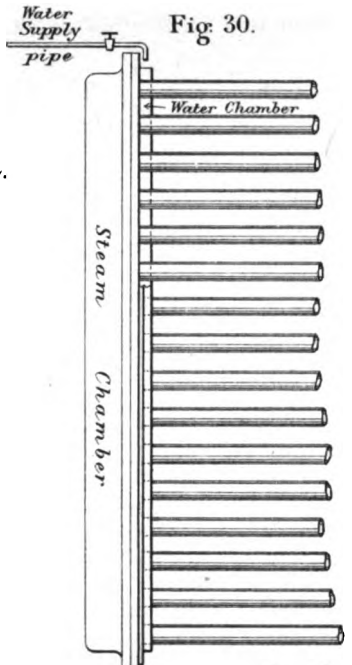


Scale 1/10th

Jointing Tubes, and Water-Seal.

Horizontal Tubes.

Fig. 30.



Scale 1/32nd

Fig. 31.

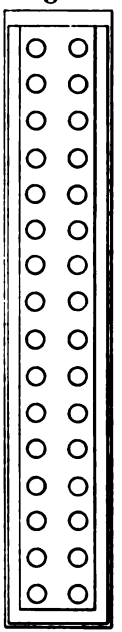
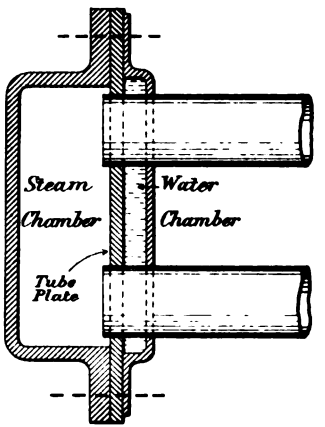


Fig. 32. *Sectional Plan.*



Scale 1/8th

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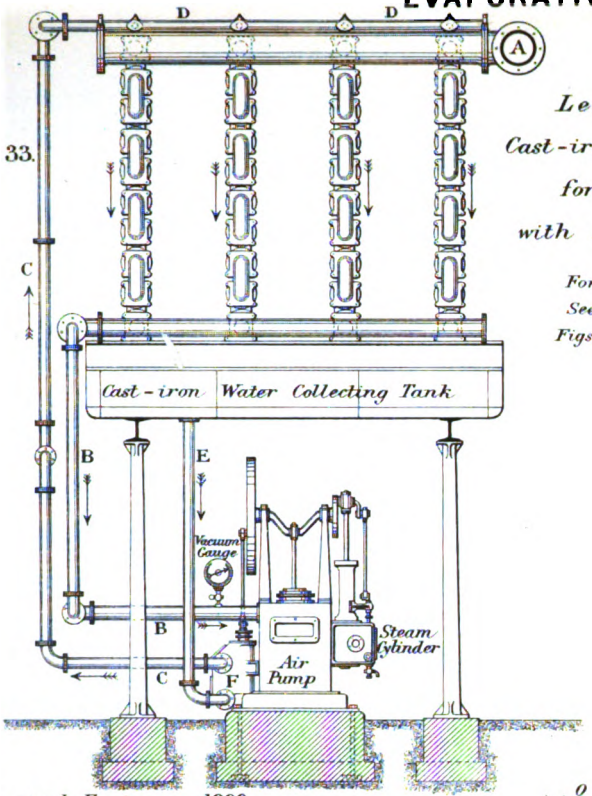
EVAPORATIVE CONDENSERS.

Plate 45.

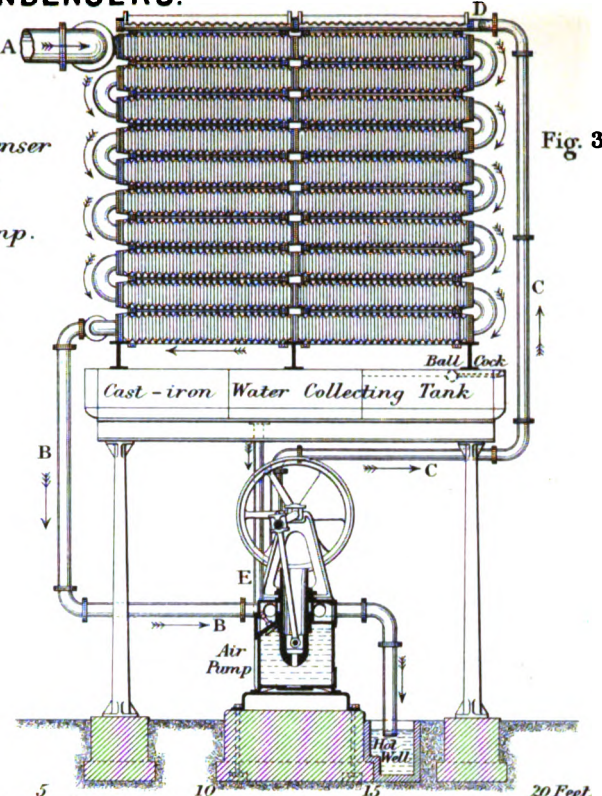
Fig. 33.



Ledward
Cast-iron Condenser
for 150 H.P.
with Air Pump.

For Detail
See Plate 42.
Figs. 18 and 19.

Fig. 34.



Mechanical Engineers 1899.

Plate 45.

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EVAPORATIVE CONDENSERS.

Ledward Evaporative Condenser.

Chapel Street, Knightsbridge.

Fig. 35.

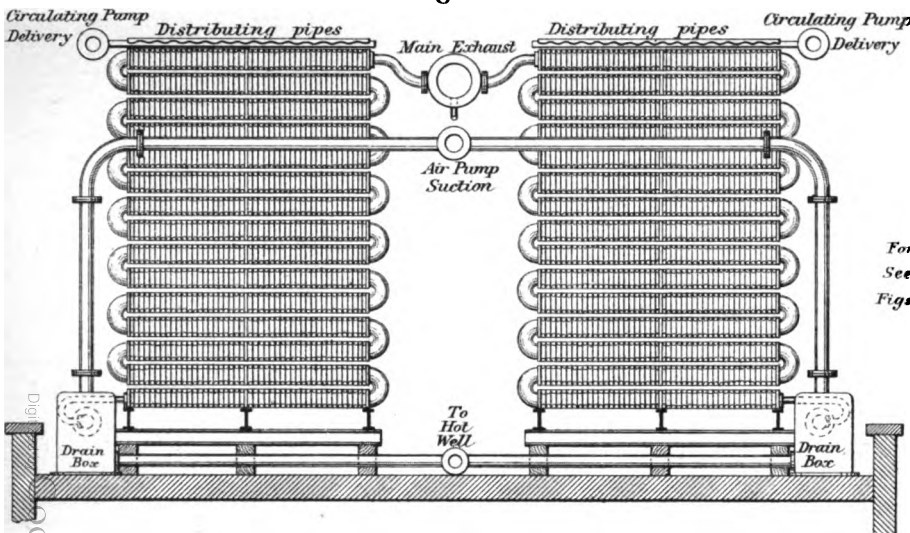

Fig. 36.

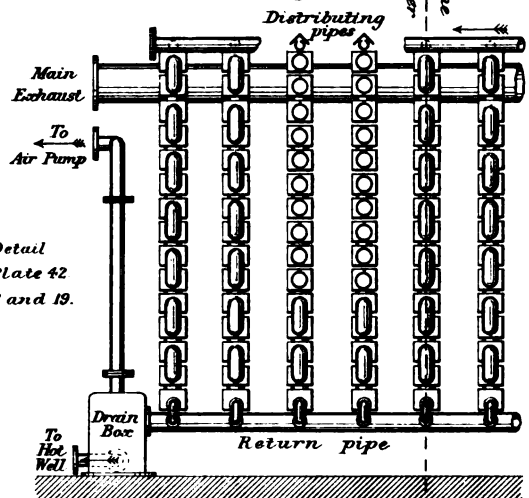

Plate 46.

0 5 10 15 20 25 30 35 Feet

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EVAPORATIVE CONDENSERS.

Plate 47.

Horizontal Cast-iron-tube Type.

Fig. 37.

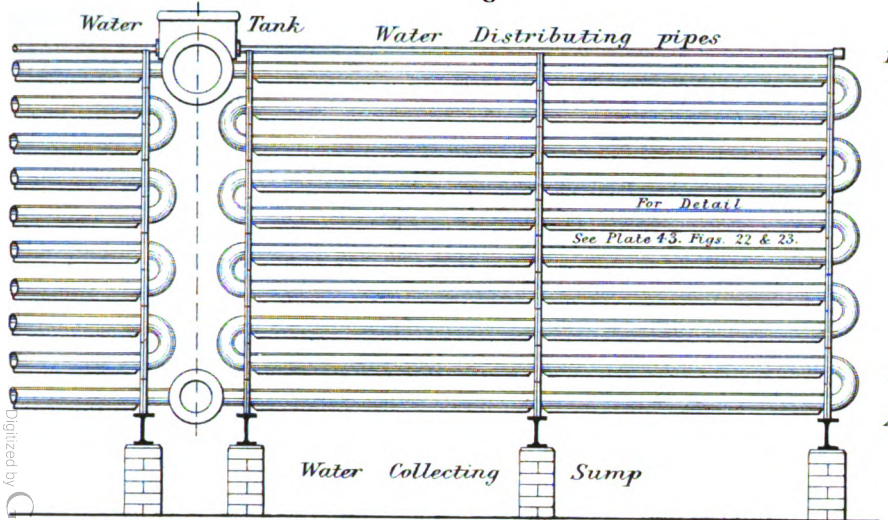
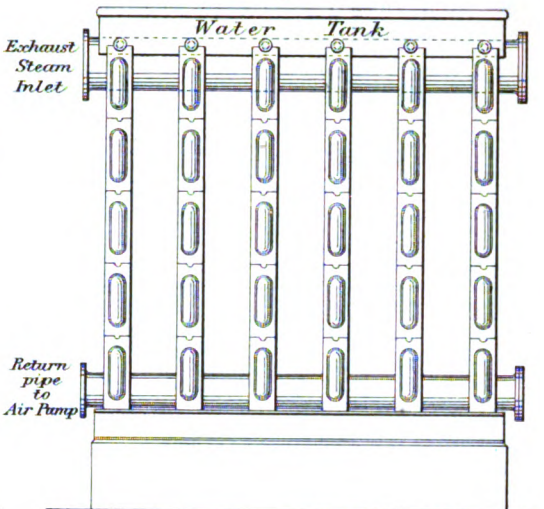


Fig. 38.



Inches 12 6 0 5 10 Feet 15

Pl. 47.

Mechanical Engineers 1899.

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EVAPORATIVE CONDENSERS.

Fraser Horizontal Wrought-iron-tube Type at Waterloo.

Fig. 39.

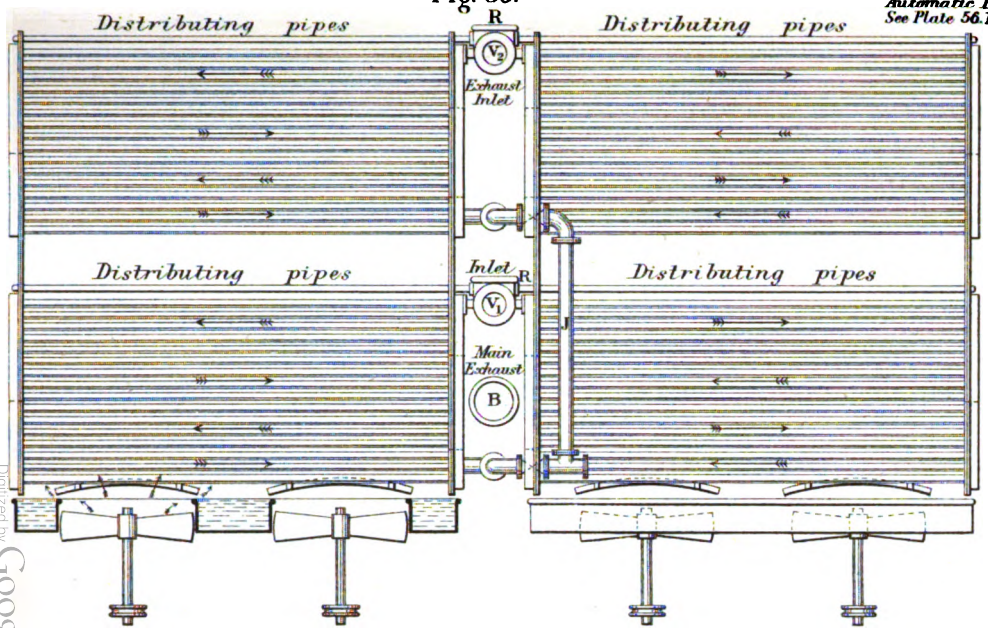

Fig. 40.

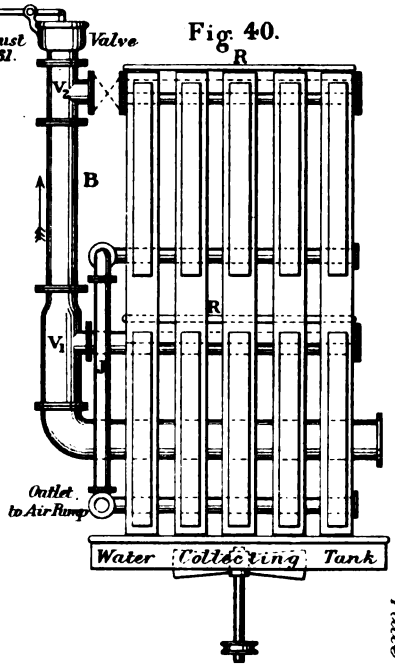

Plate 48.

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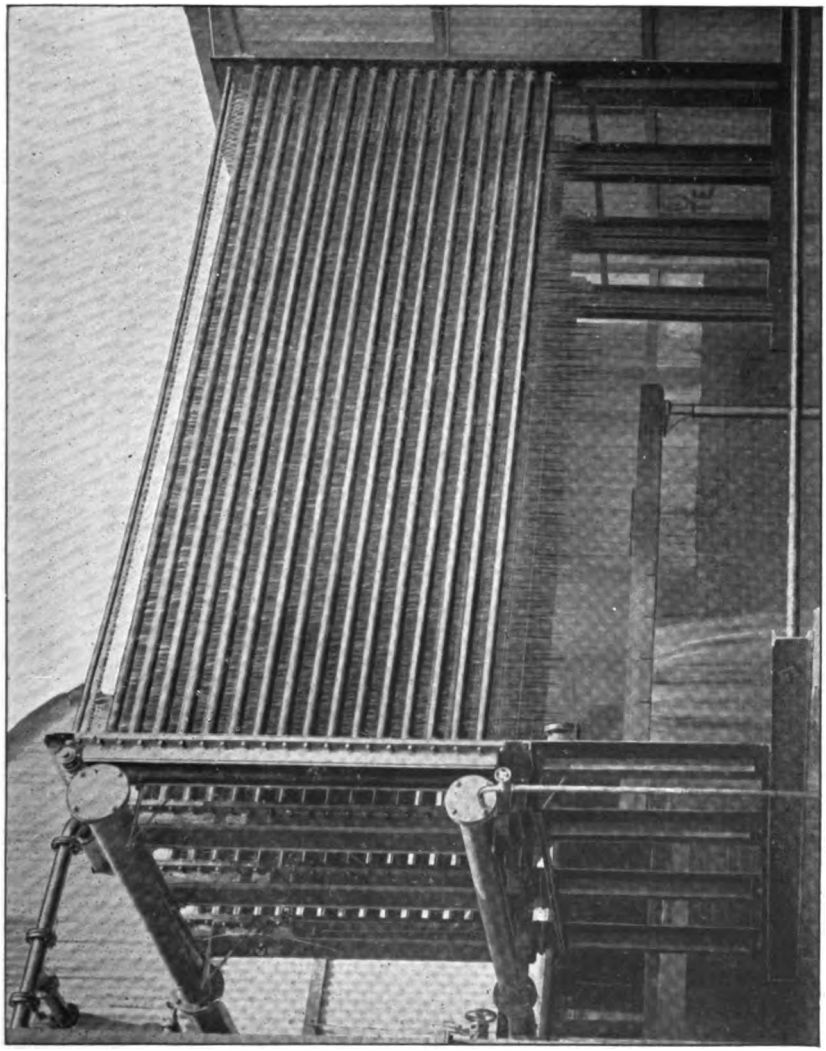
Fig. 41.

Fraser Horizontal Type at Blackpool showing Water circulating over Tubes.



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EVAPORATIVE CONDENSERS.

Fraser Vertical Brass-tube Type. Blackpool.

Fig. 42.

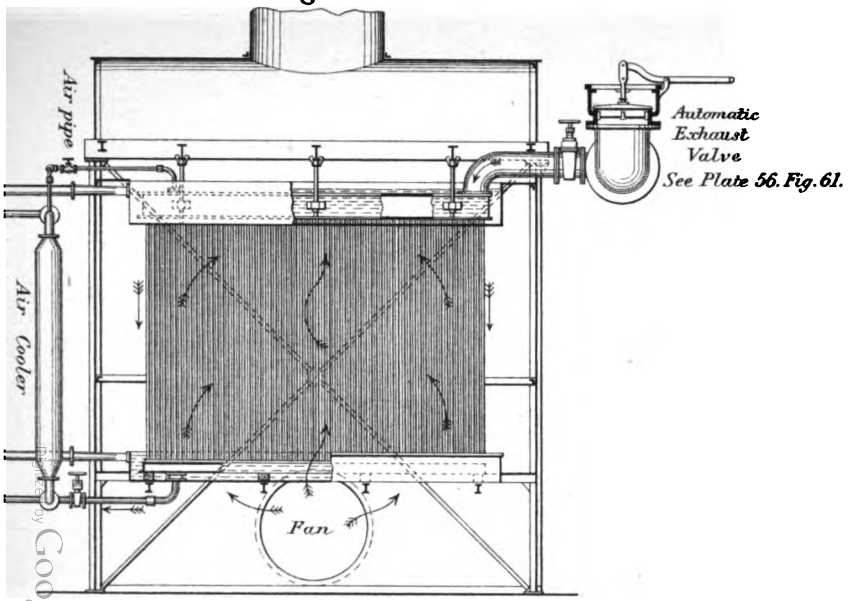
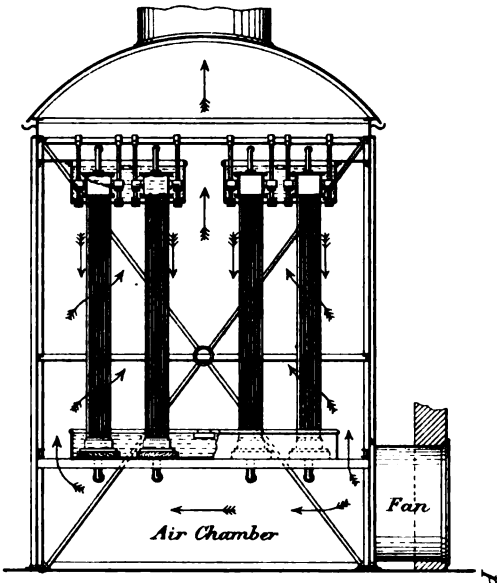


Fig. 43.



0 5 10 15 20 25 Feet

echanical Engineers 1899.

Plate 50.

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EVAPORATIVE CONDENSERS.

Plate 51.

Circular Types.

Fig. 44. *Fraser.*

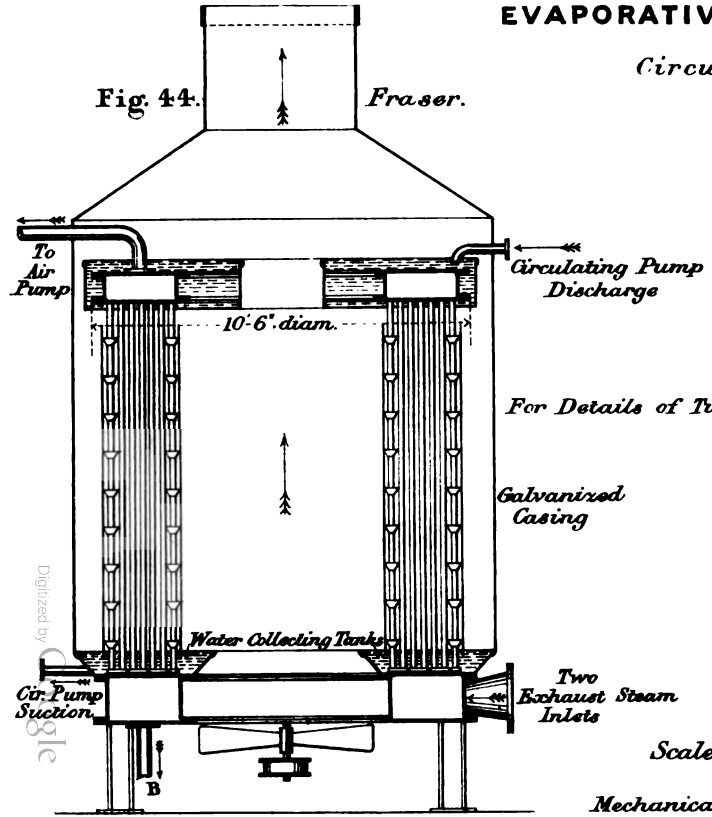
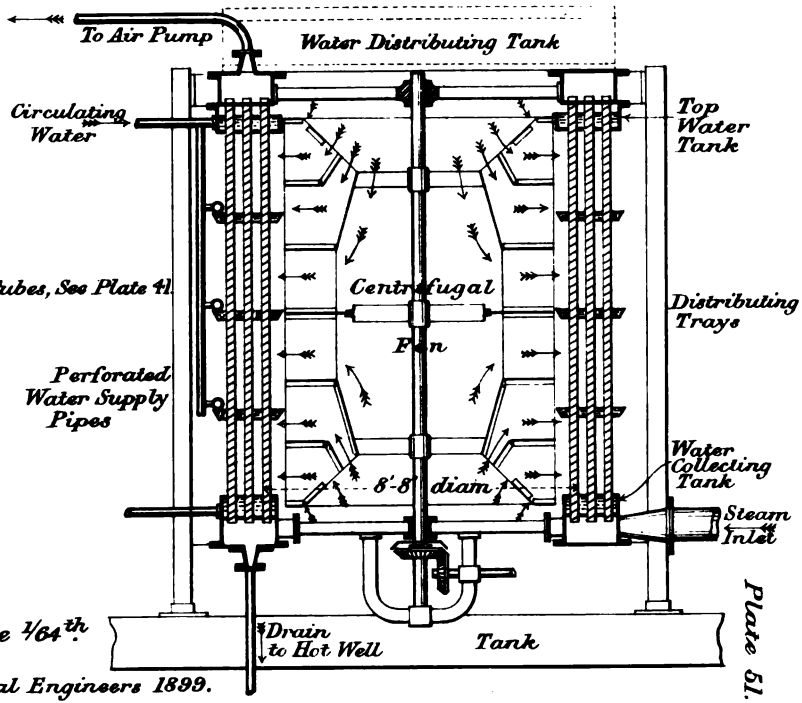


Fig. 45. *Theisen.*



Scale 1/64th.

Mechanical Engineers 1899.

Plate 51.

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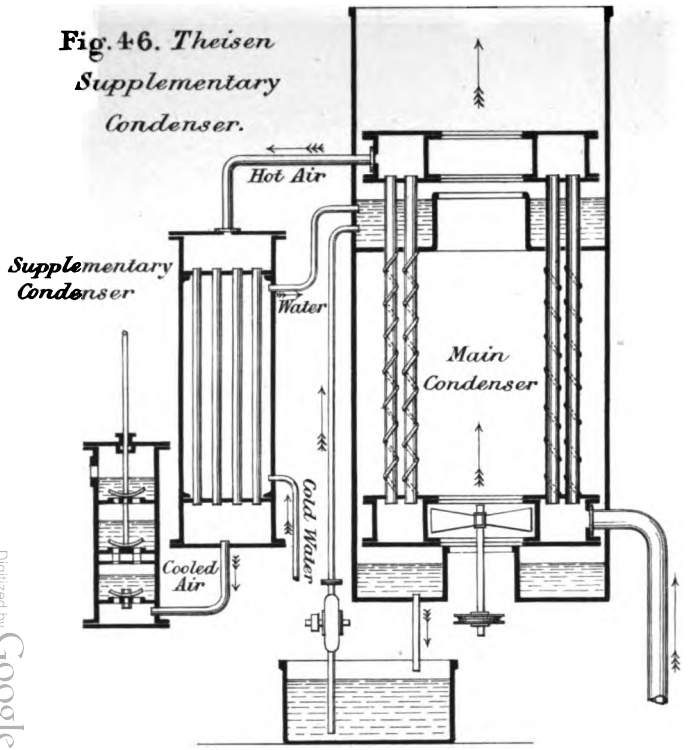

Fig. 46. *Theisen Supplementary Condenser.*

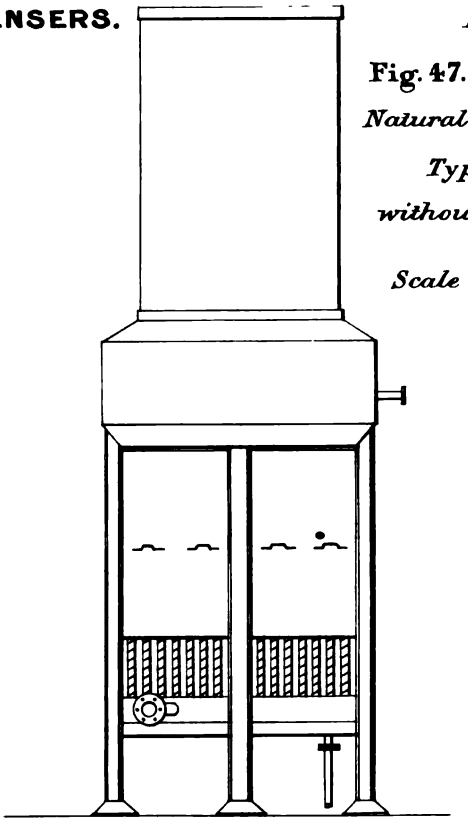

Fig. 47. *Theisen Natural Draught Type, without fan.*

Scale 1/64th.

Plate 52.

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Wright Vertical Brass-tube Type for 500 H.P.

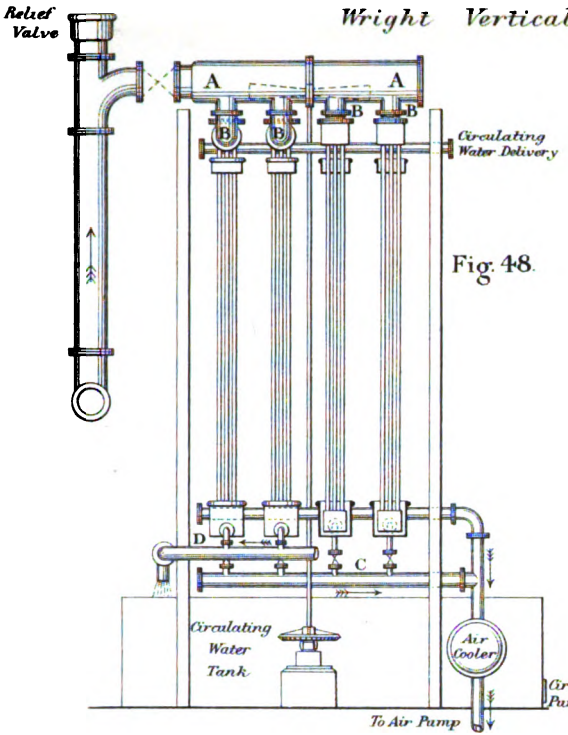

Fig. 48.

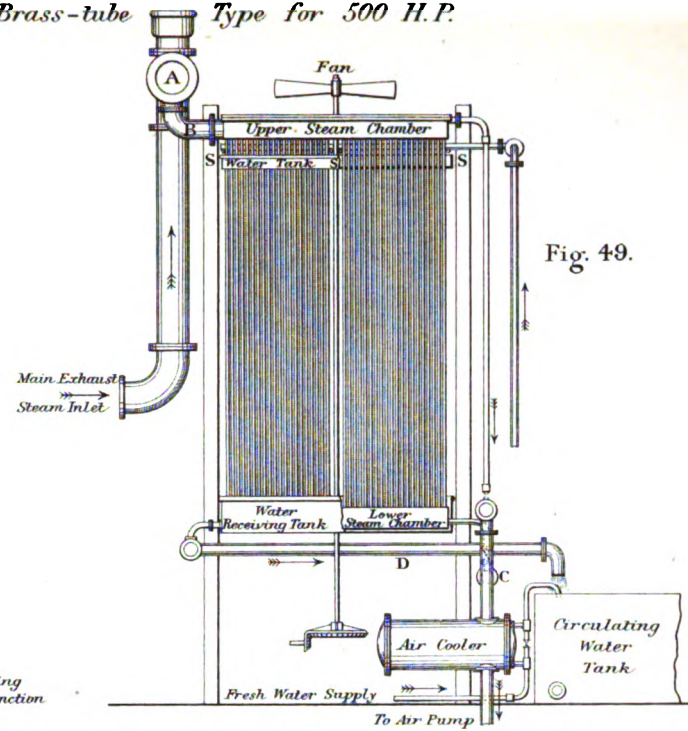

Fig. 49.

Plate 53.

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EVAPORATIVE CONDENSERS.

Comparative Methods of leading water over Tubes.

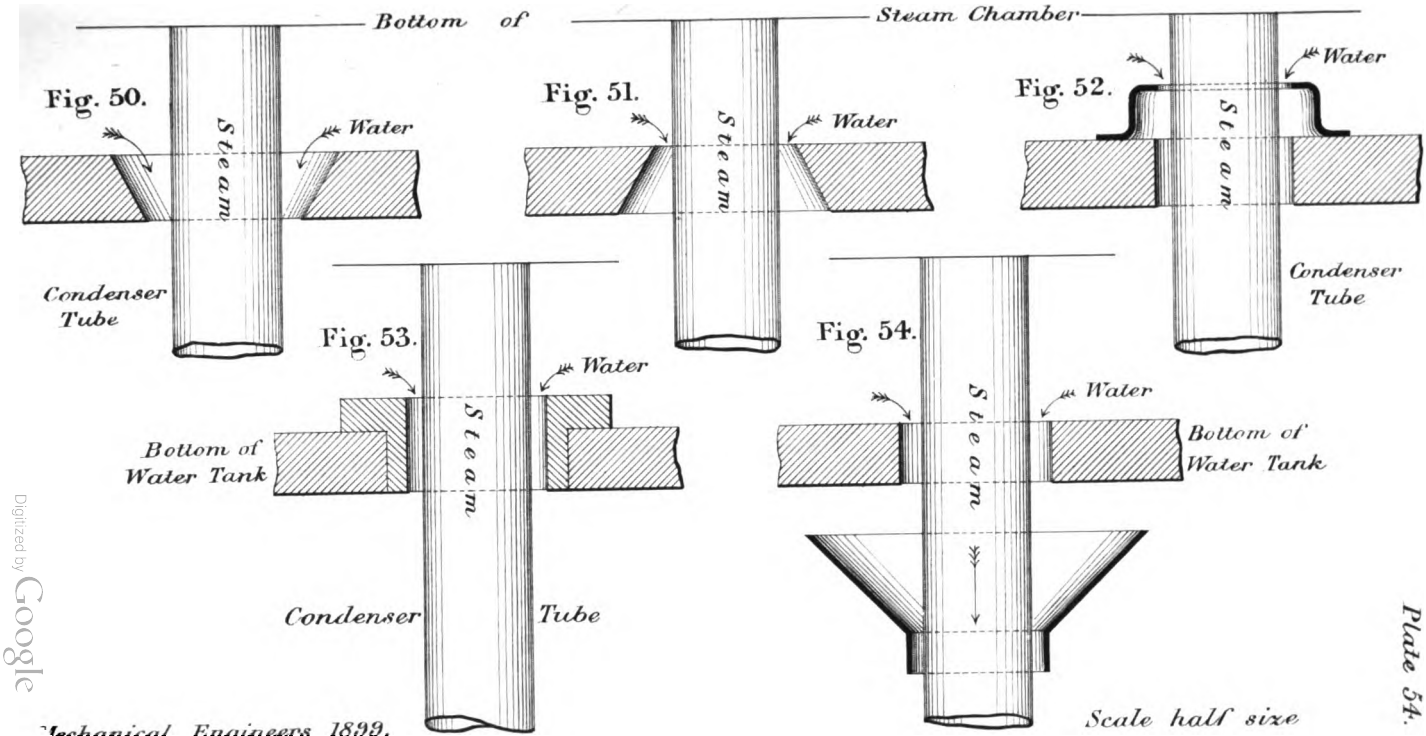

Plate 54.

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EVAPORATIVE CONDENSERS.

Horizontal Wrought-iron-tube Condenser. *Erected about 1872 in Lambeth.*

Fig: 55.

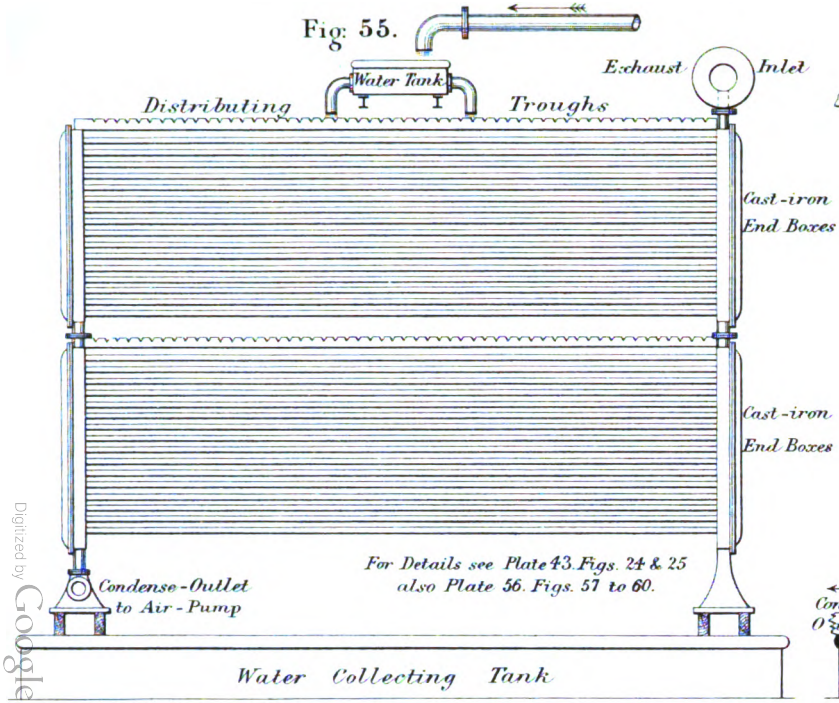
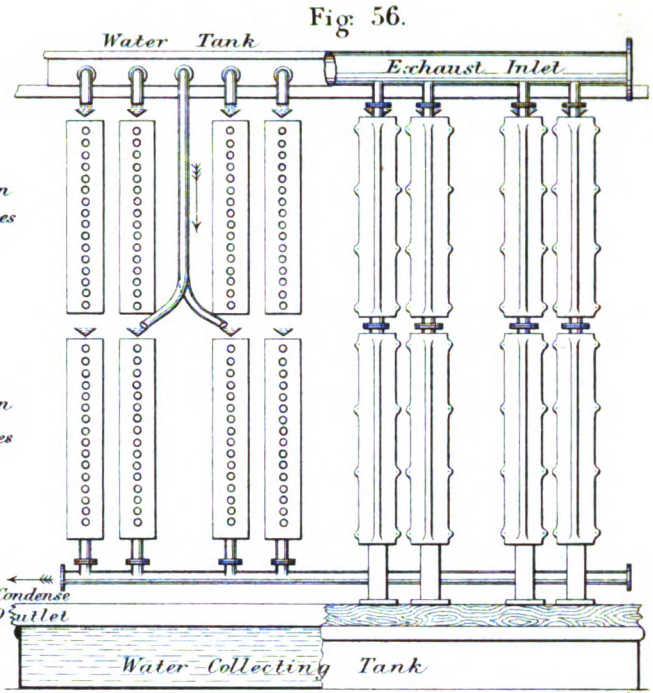


Fig: 56.



Pl. 55.

Mechanical Engineers 1899.

Scale 1/48th

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Distributing Trough, see Figs. 55 *and* 56.

Fig. 57.

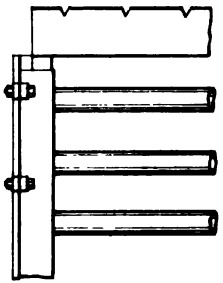
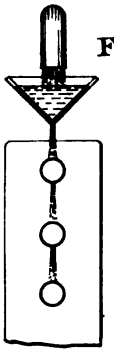


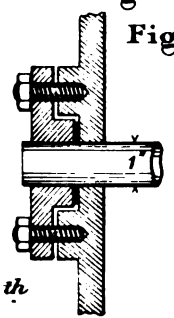
Fig. 58.



Rubber Joint, see Figs. 55 *and* 56.

Fig. 59.

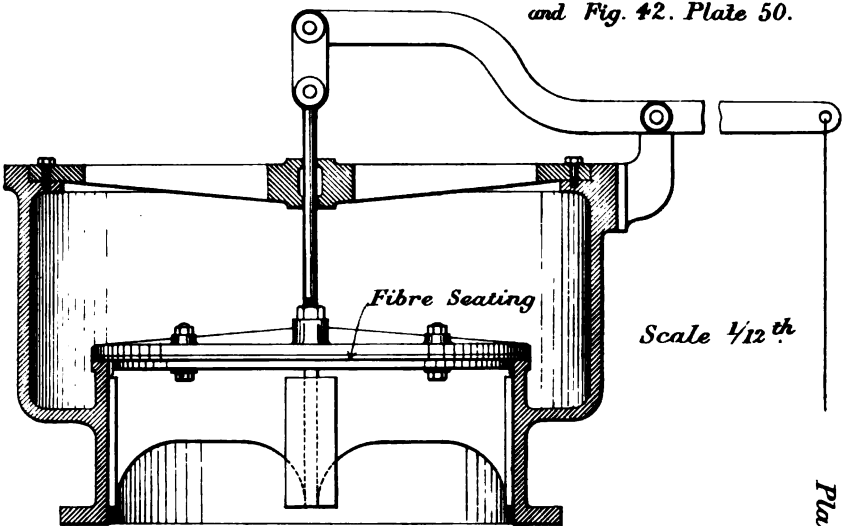
Fig. 60.



Scale 1/4 th.

Fig. 61.

Automatic Exhaust Valve, see Fig. 40. *Plate 48, and Fig. 42. Plate 50.*



Scale 1/12 th.

Plate 56.

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EVAPORATIVE CONDENSERS.

Plate 57.

Kirkaldy Horizontal Wrought-iron-tube Type.

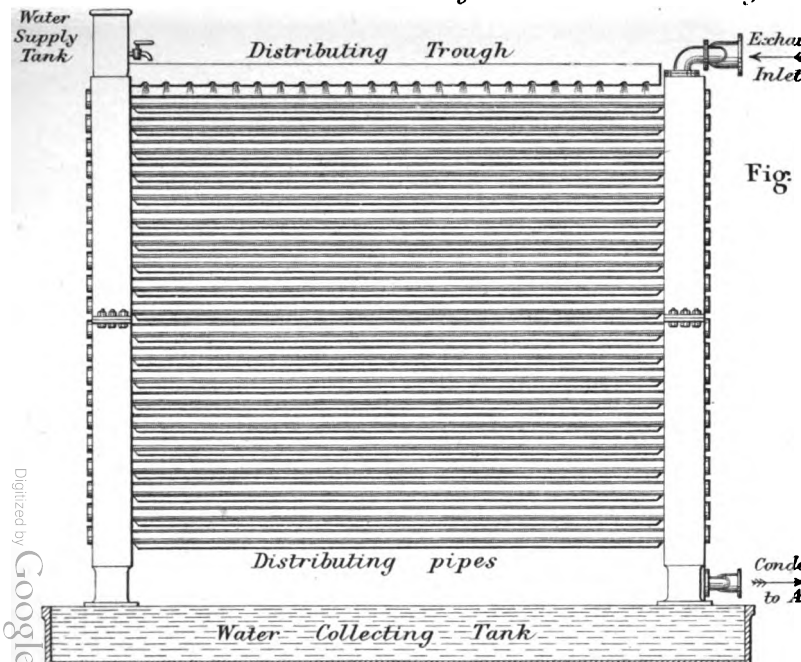

Fig. 62.

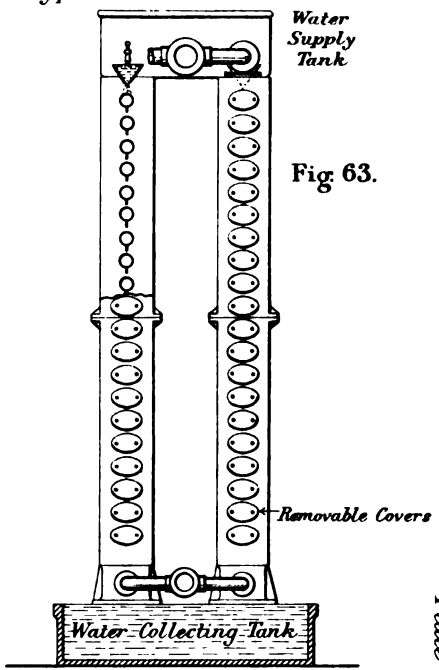

Fig. 63.

Mechanical Engineers 1899.

Scale 1/48th.

Plate 57.

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EVAPORATIVE CONDENSERS. *Plate 58.*

Vertical cast-iron-tube Type.

Fig. 64.

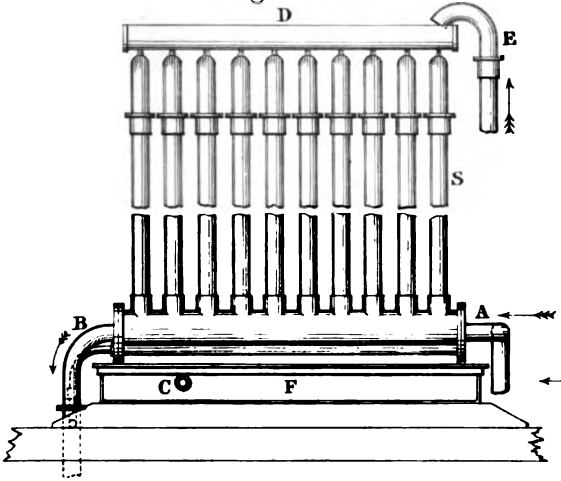


Fig. 65.

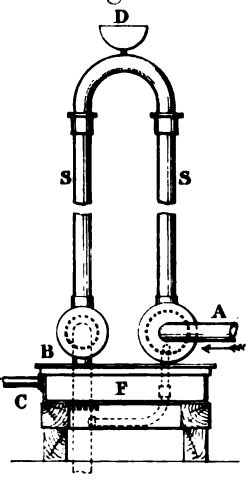
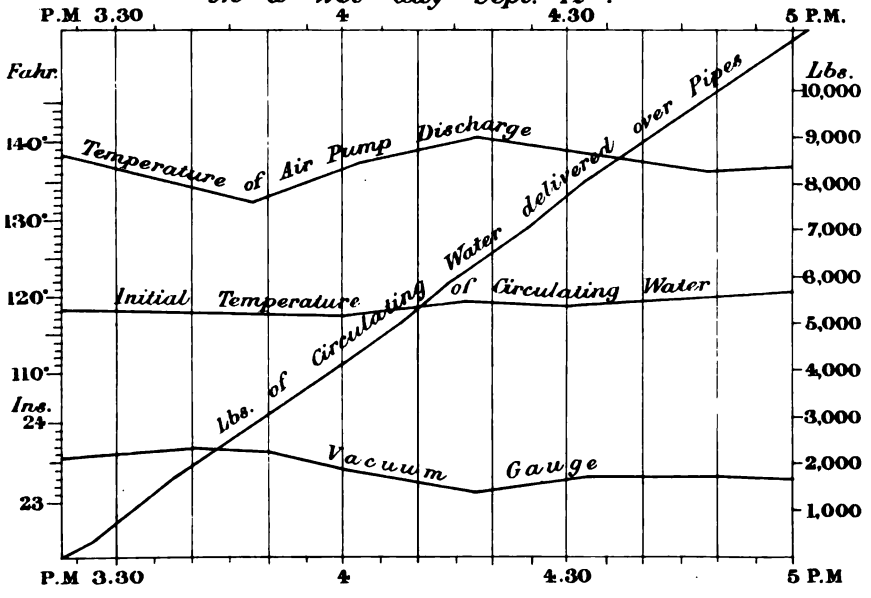


Fig. 66. *Results obtained from above Condensers. on a wet day Sept. 12th.*



Mechanical Engineers 1889.

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EVAPORATIVE CONDENSERS. *Plate 59.*

Row Condenser.

Fig. 67.

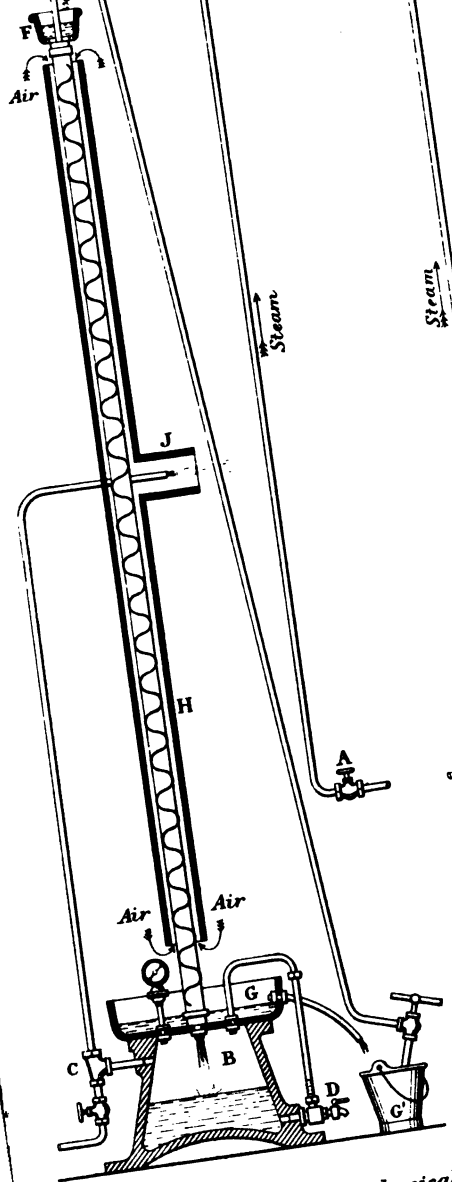
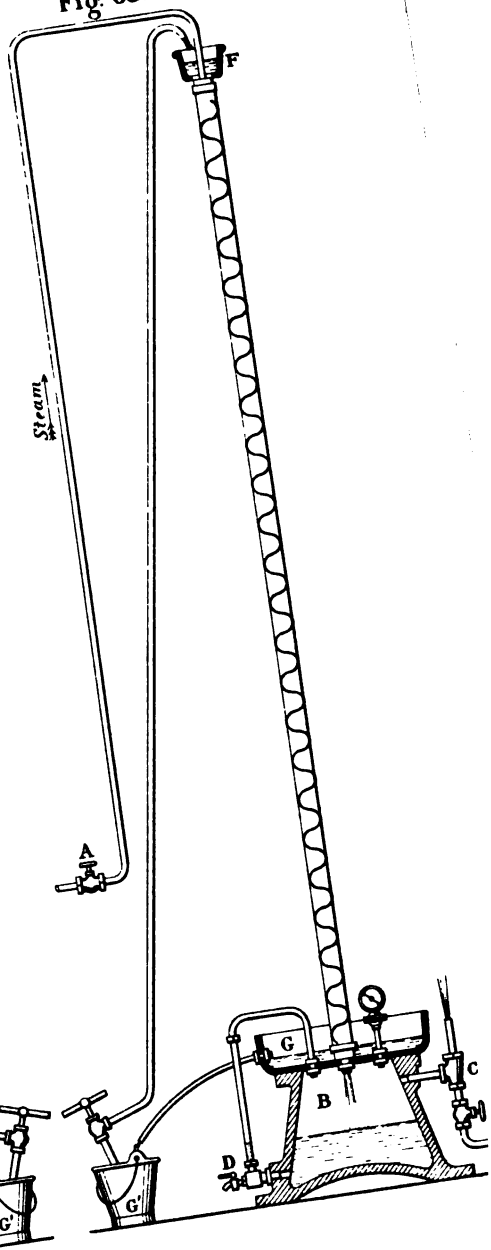


Fig. 68.



Mechanical Engineers 1899.

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Row Condenser.

For Detail, see Plate 41. Figs. 7 and 8.

Fig. 69.

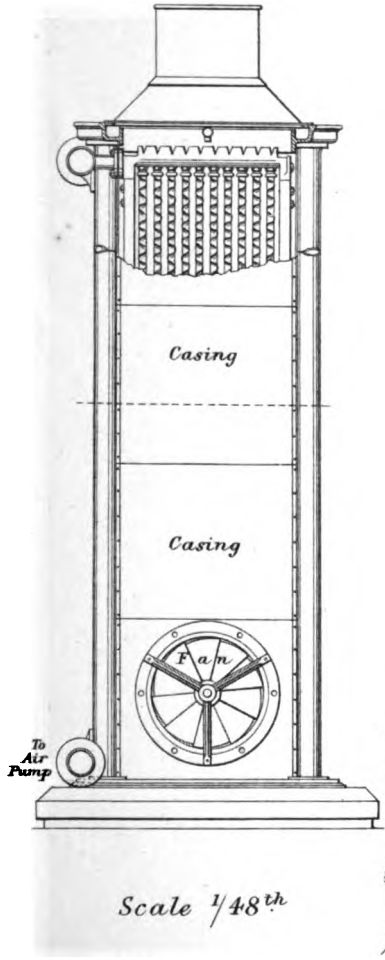
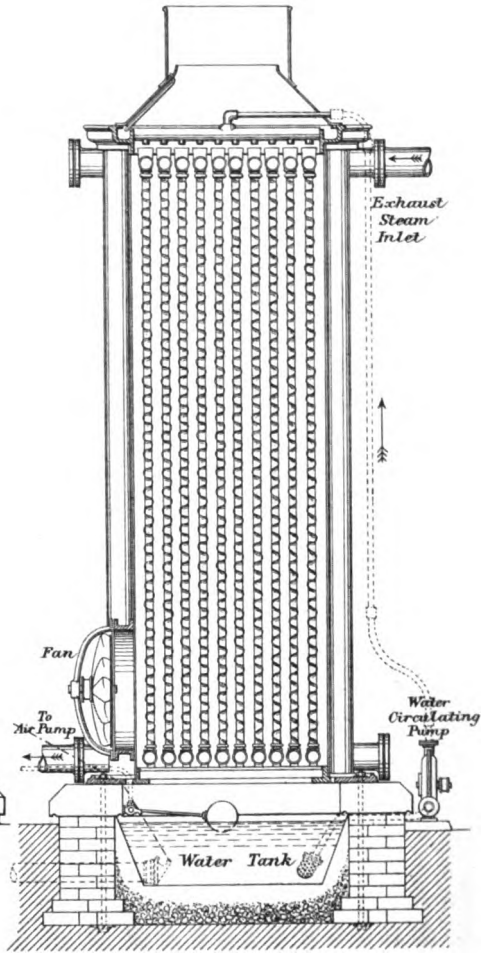


Fig. 70.



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EVAPORATIVE CONDENSERS.

Diagrams of Forced and Induced Air Circulation.

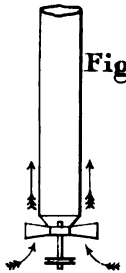
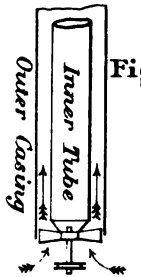


Fig. 71.



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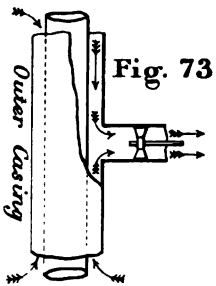

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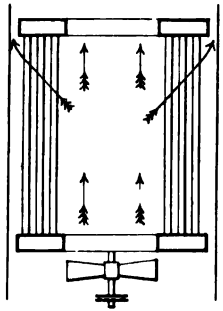

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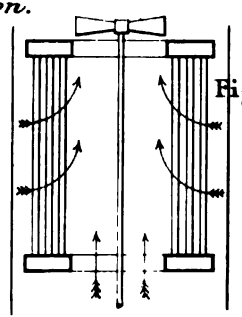

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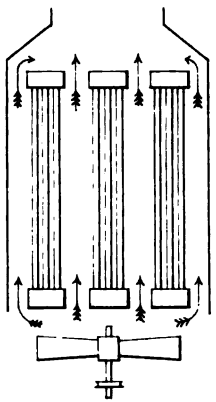

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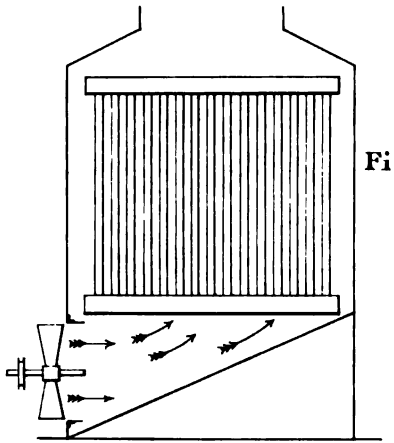

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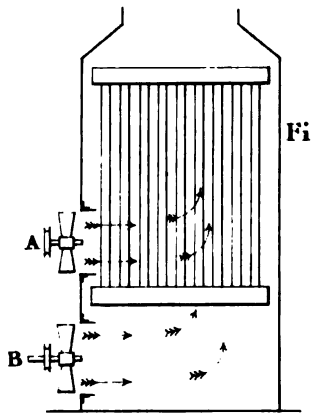

Fig. 78.

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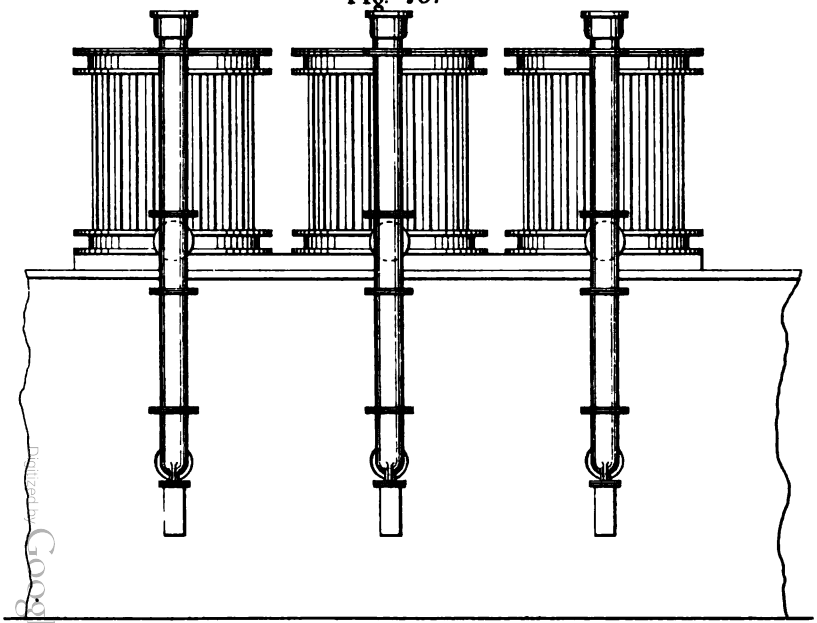
Diagram of General Arrangement of Condenser.

Fig. 79.



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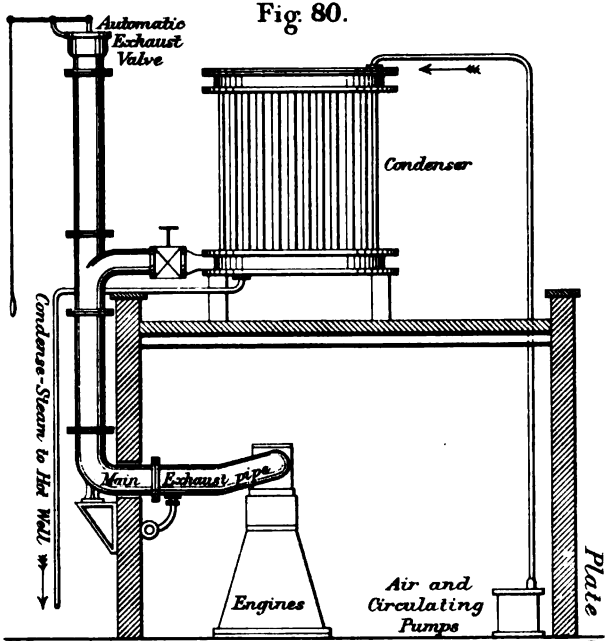

Plate 62.

Mechanical Engineers 1899.

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EVAPORATIVE CONDENSERS. *Plate 63.*

Kynoch Tube.

Fig: 81.

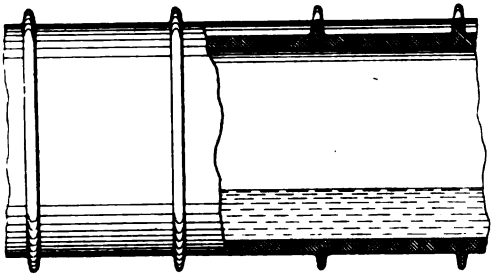


Fig: 82.

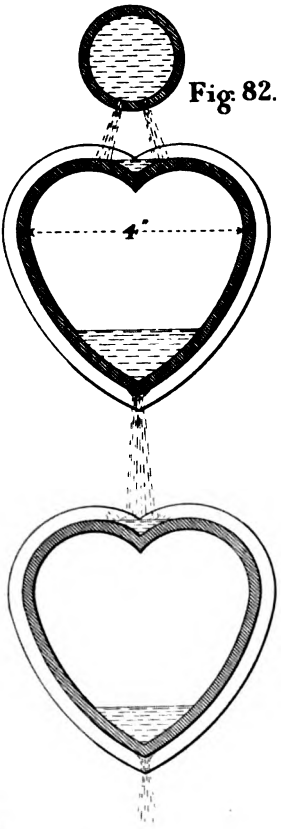
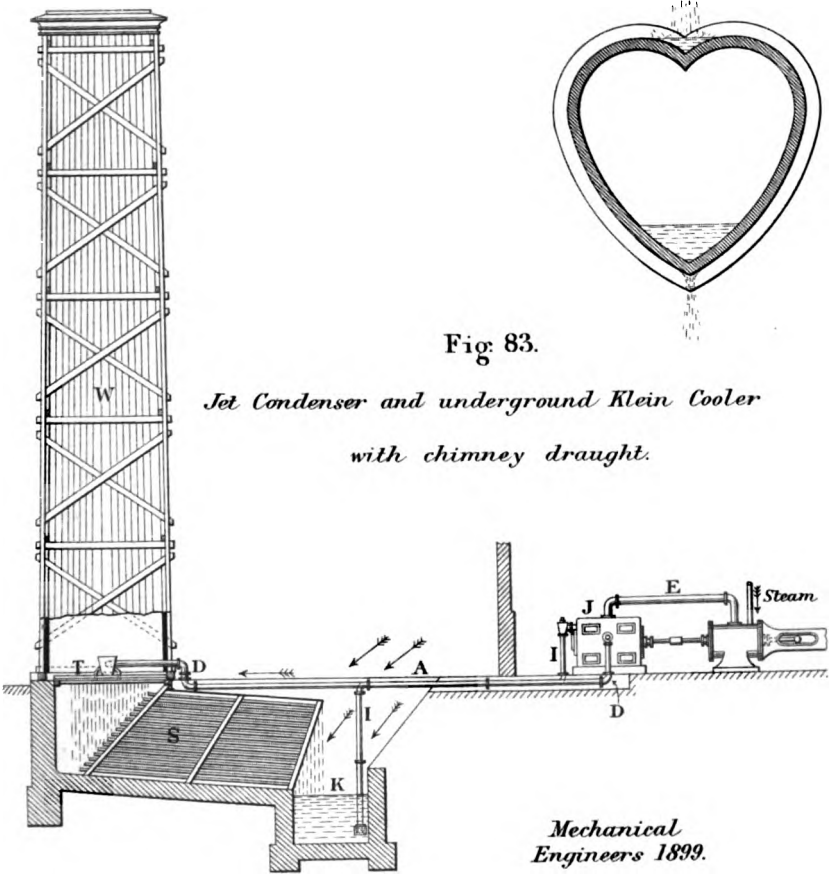


Fig: 83.

Jet Condenser and underground Klein Cooler with chimney draught.



Mechanical Engineers 1899.

Feet 10 0 10 20 30 40 5

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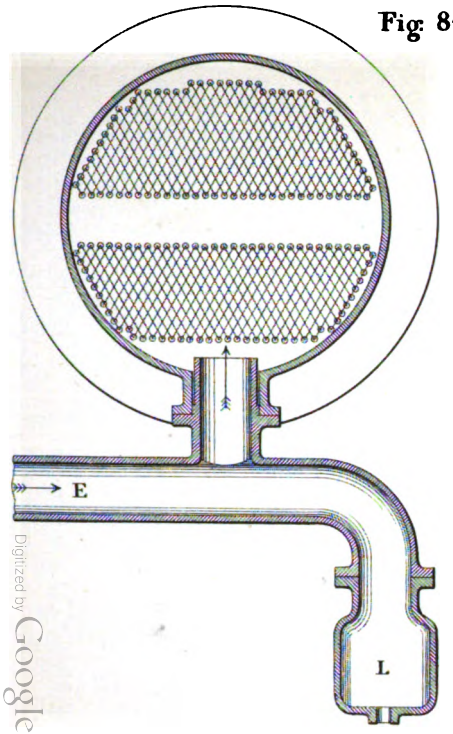
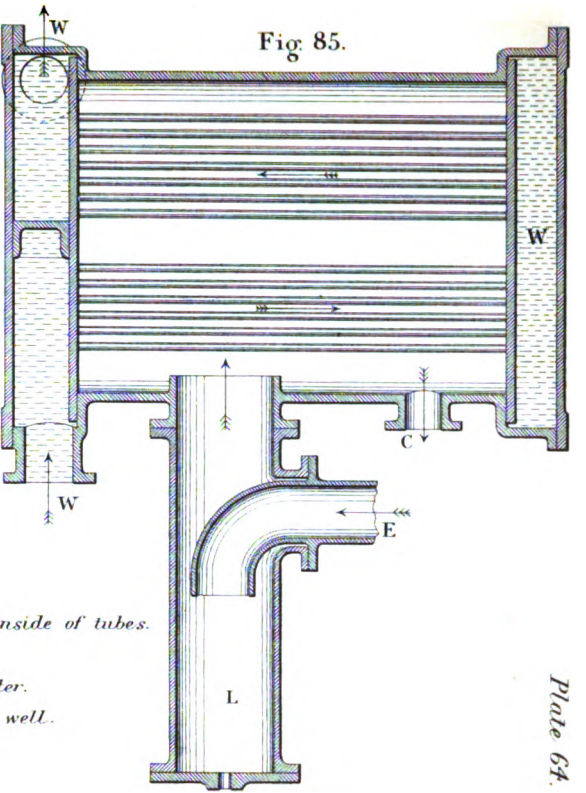
Fig. 84.



Arrangements for collecting waste oil.

Fig. 85.



W = *cooling water flowing through inside of tubes.*
E = *exhaust steam from engine.*
L = *well for catching oil and water.*
C = *condensed steam flowing to hot well.*

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Plate 64.

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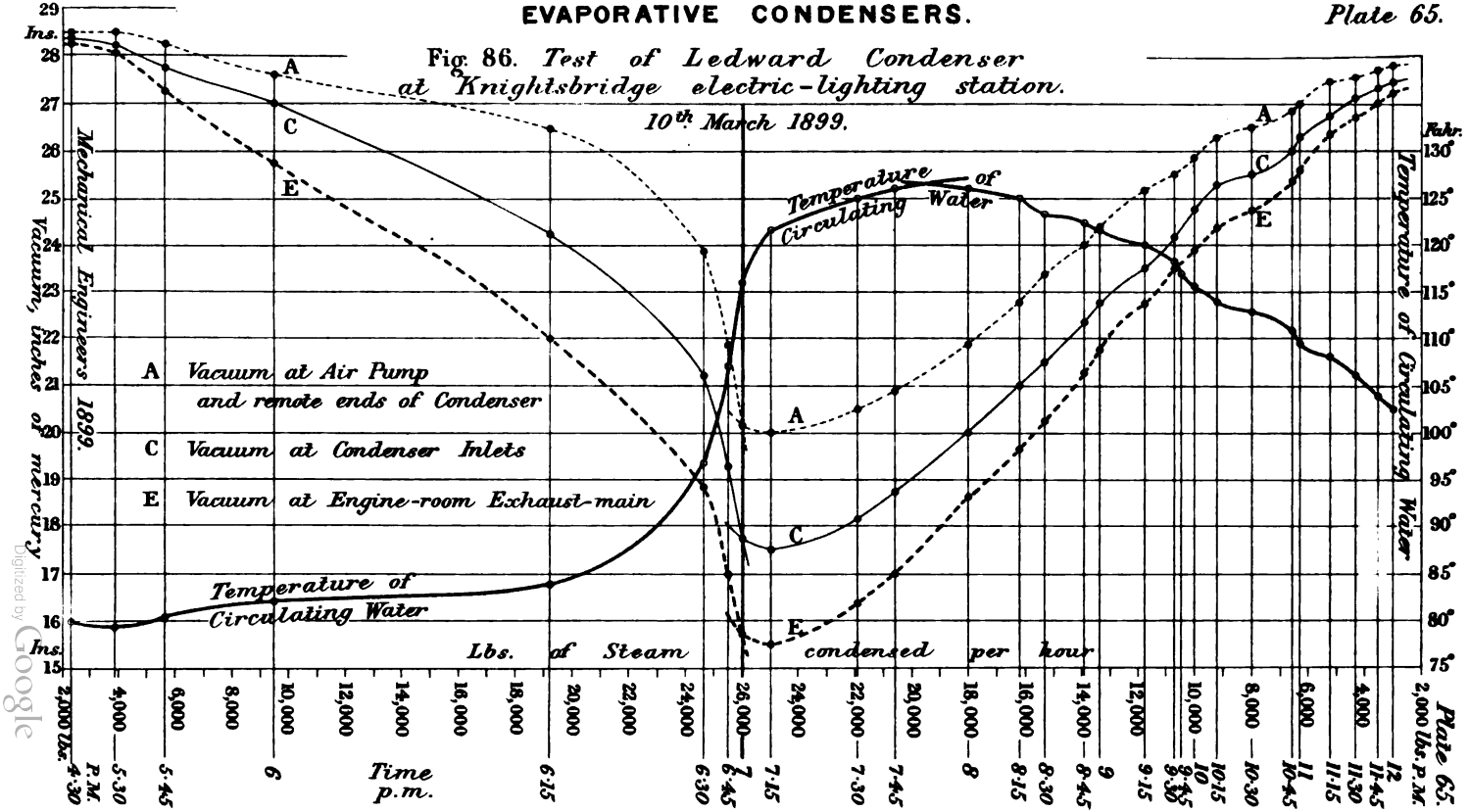
Fig. 86. *Test of Ledward Condenser at Knightsbridge electric-lighting station.*

10th March 1899.



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Ammonia and Steam Condenser.

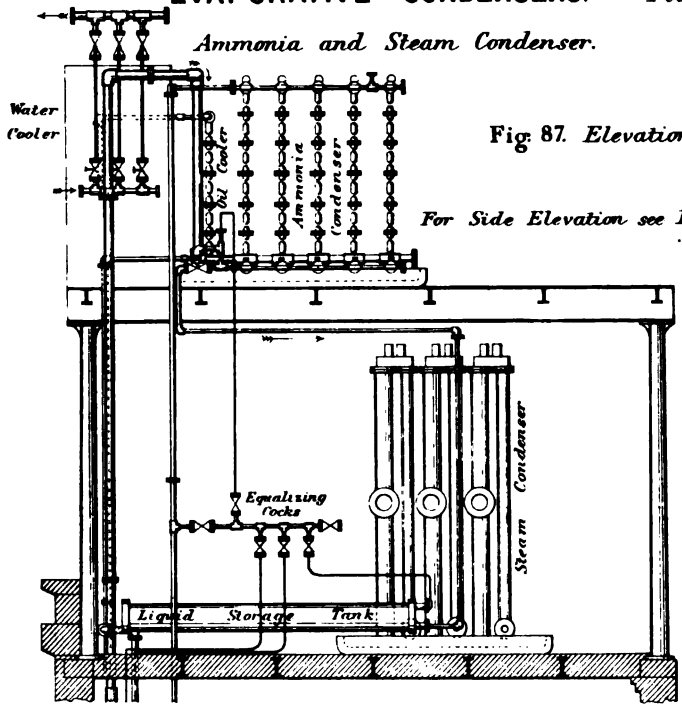
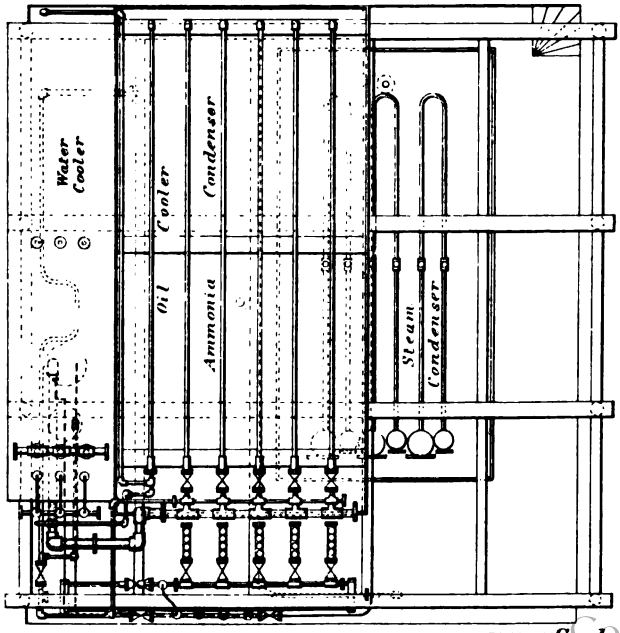


Fig. 87. *Elevation.*

For Side Elevation see Plate 67.

Fig. 88. *Plan.*



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EVAPORATIVE CONDENSERS.

Plate 62.

Diagram of General Arrangement of Condenser.

Fig. 79.

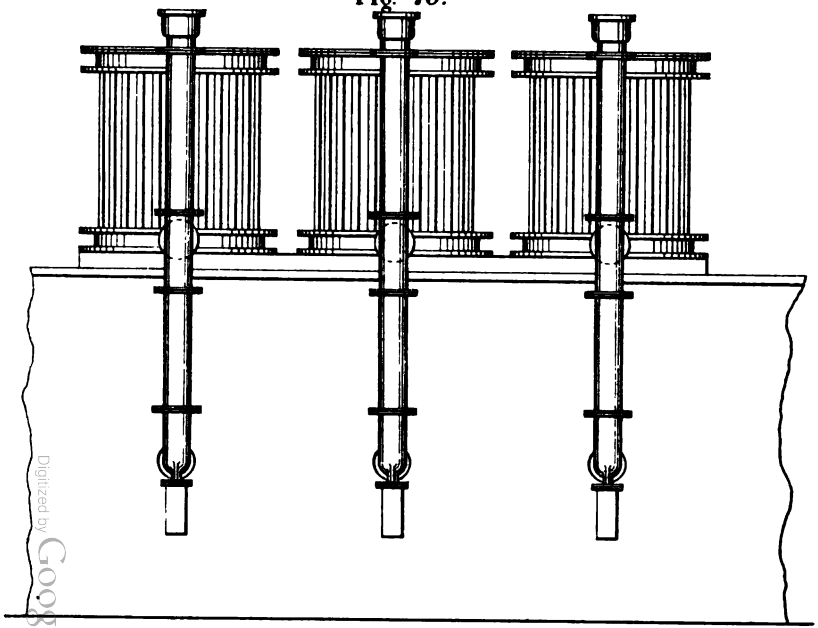

Fig. 80.

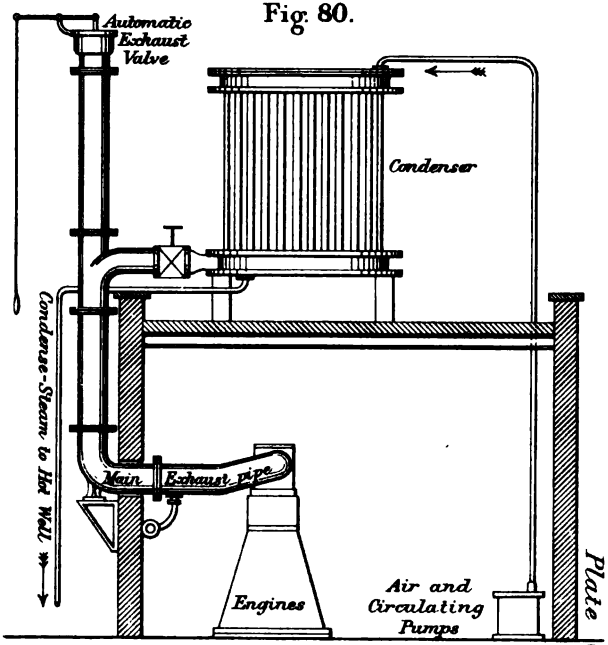

Plate 62.

Mechanical Engineers 1899.

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Kynoch Tube.

Fig: 81.

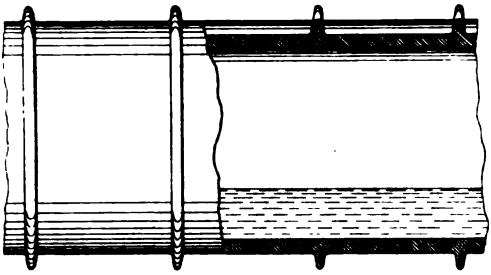


Fig: 82.

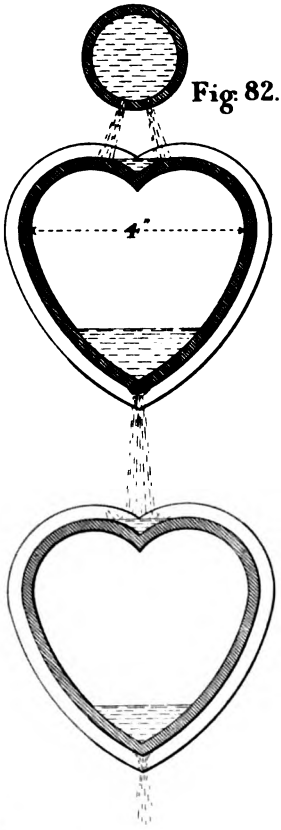
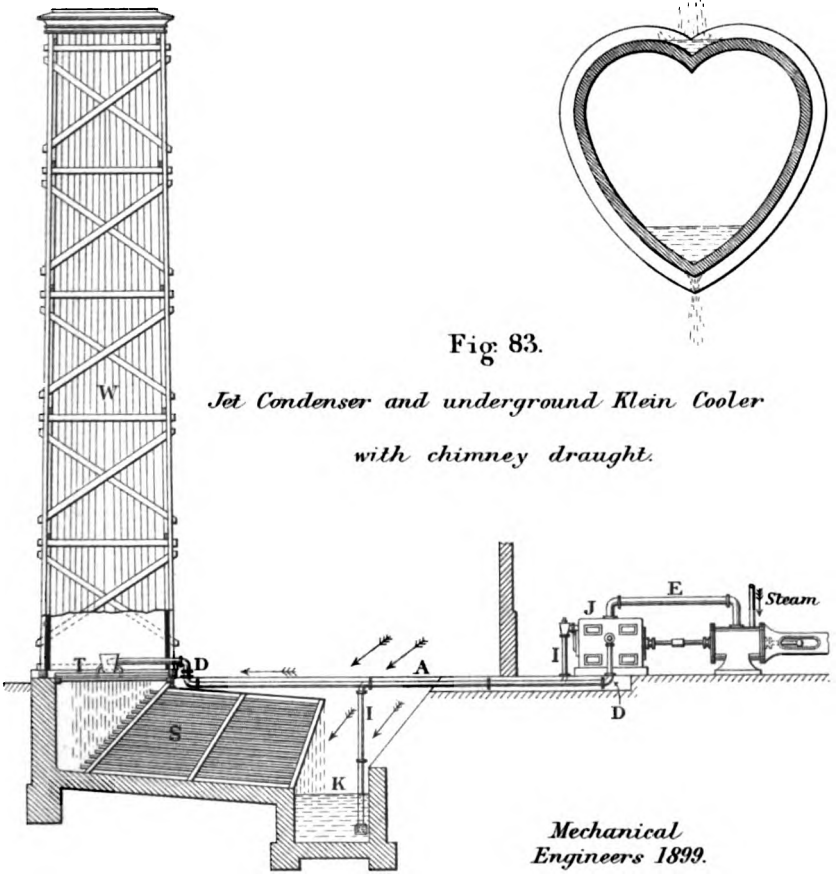


Fig: 83.

Jet Condenser and underground Klein Cooler with chimney draught.



Mechanical Engineers 1899.

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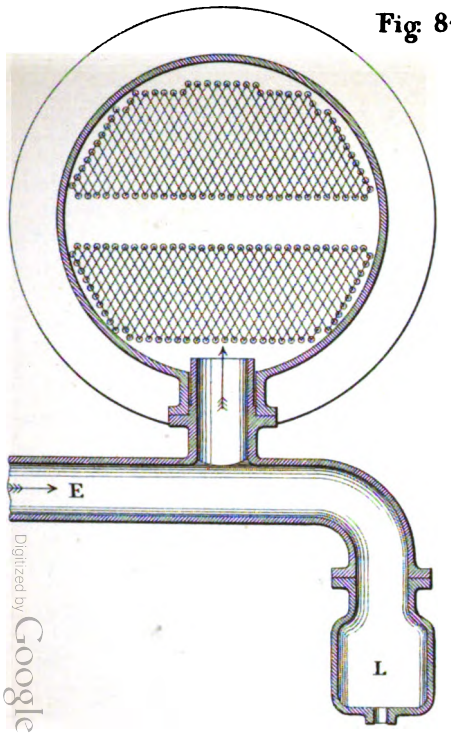
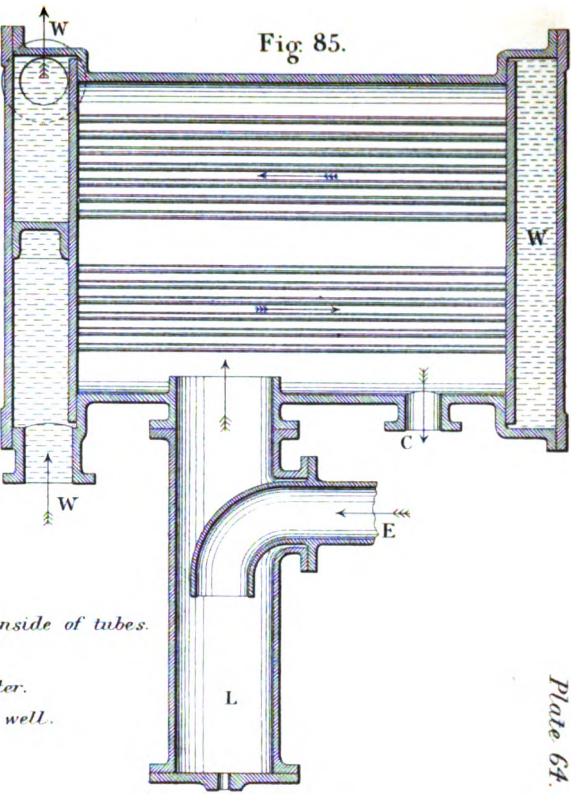
Fig. 84.



Arrangements for collecting waste oil.

Fig. 85.



W = *cooling water flowing through inside of tubes.*
E = *exhaust steam from engine.*
L = *well for catching oil and water.*
C = *condensed steam flowing to hot well.*

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Plate 64.

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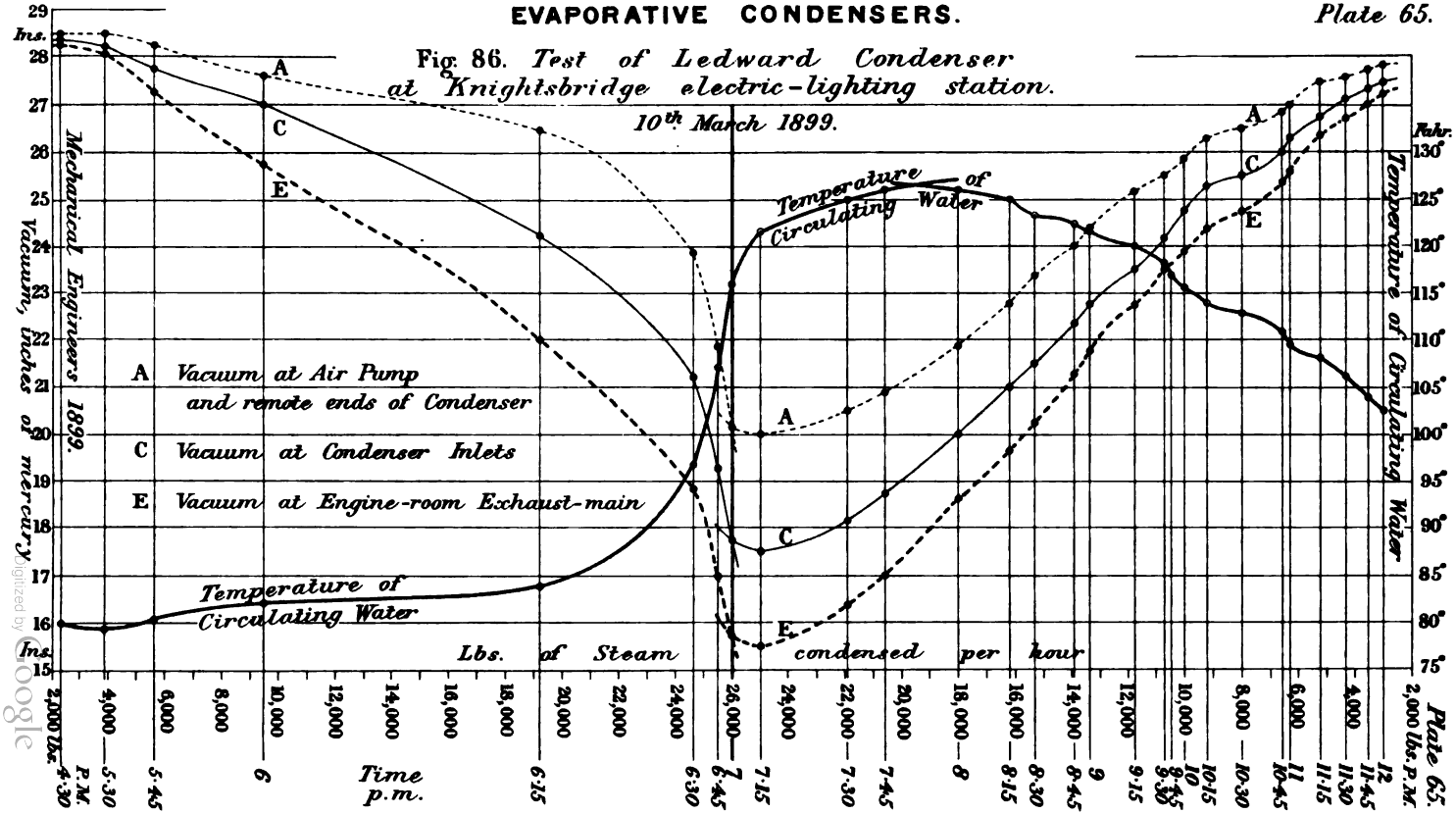
Fig. 86. *Test of Ledward Condenser at Knightsbridge electric-lighting station.*

10th March 1899.



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Ammonia and Steam Condenser.

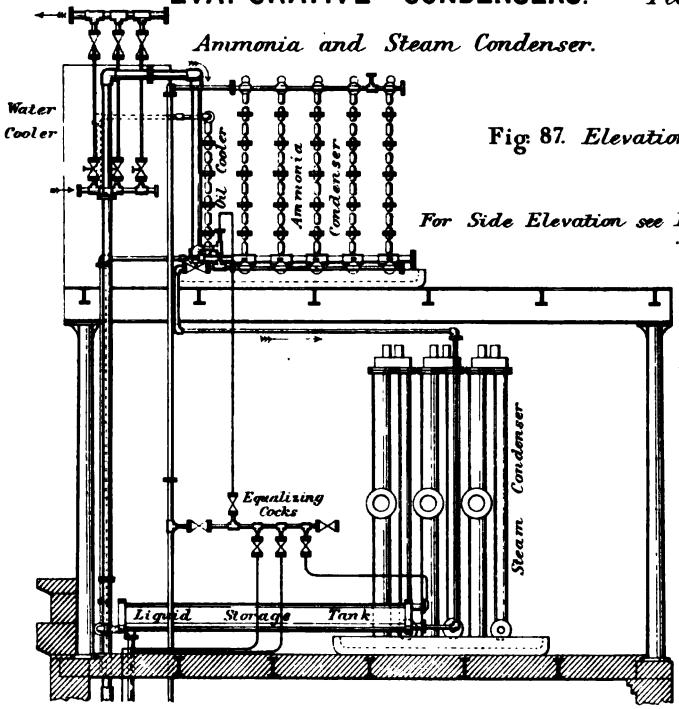
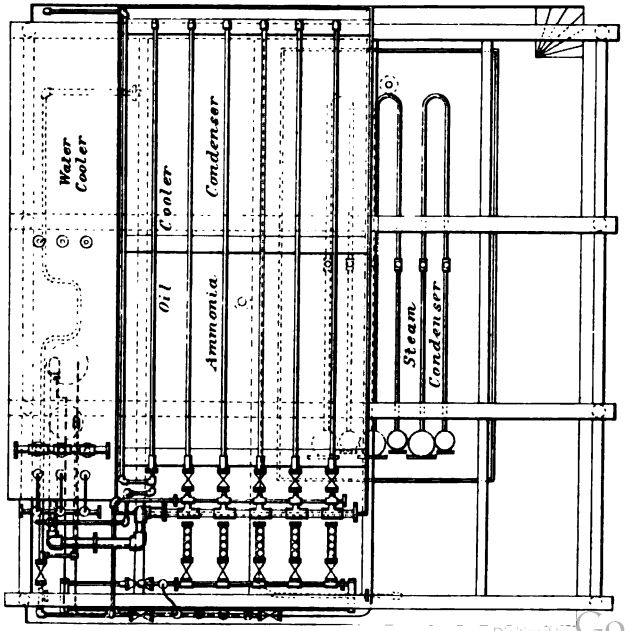


Fig. 87. *Elevation.*

For Side Elevation see Plate 67.

Fig. 88. *Plan.*



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Ammonia and Steam Condenser.

Fig. 89. *Side Elevation.*

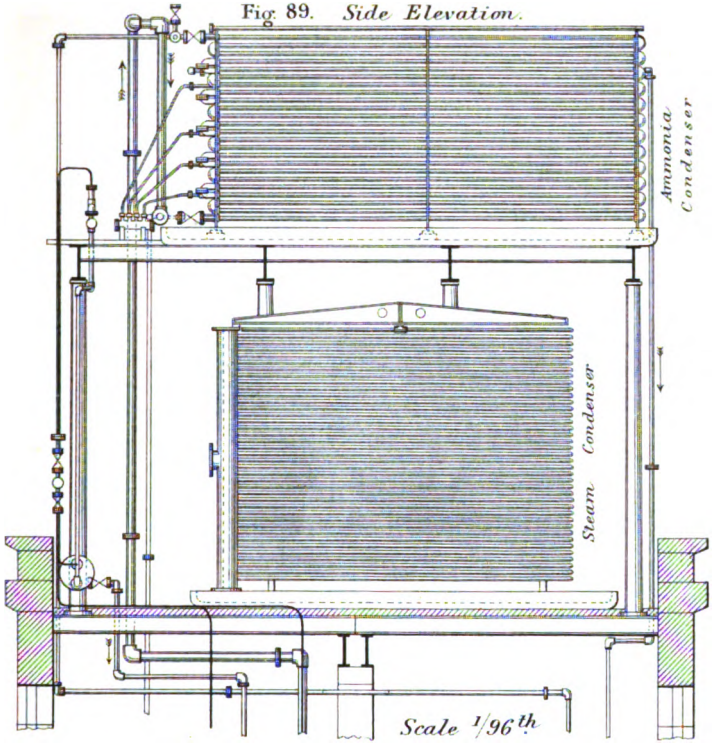
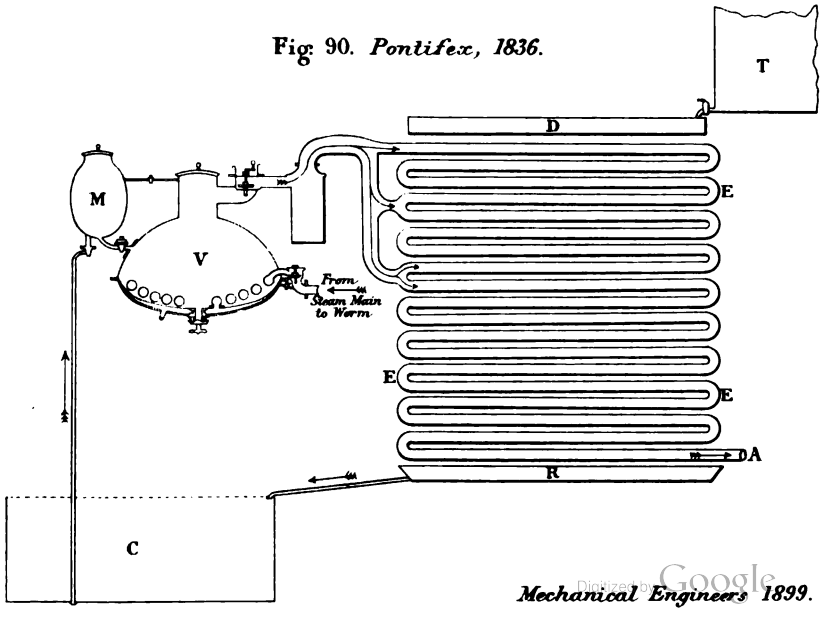


Fig. 90. *Pontifex, 1836.*



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EVAPORATIVE CONDENSERS.

Plate 68.

Cochrane Condenser.

Fig. 91.

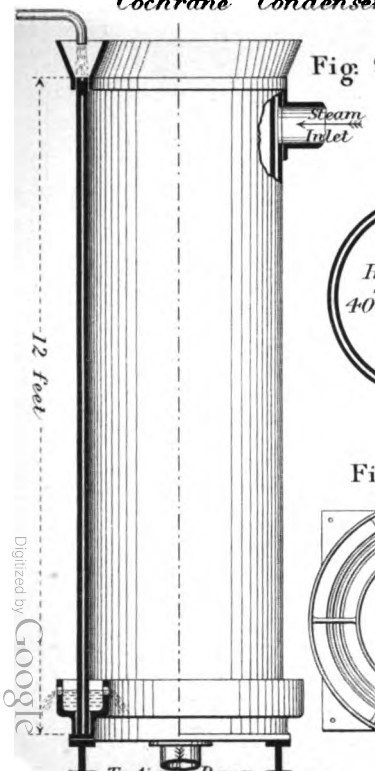
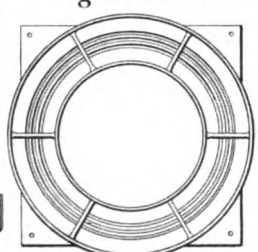


Fig. 92. *Section.*

Fig. 93. *Plan.*



Murray Condenser.

Fig. 94.

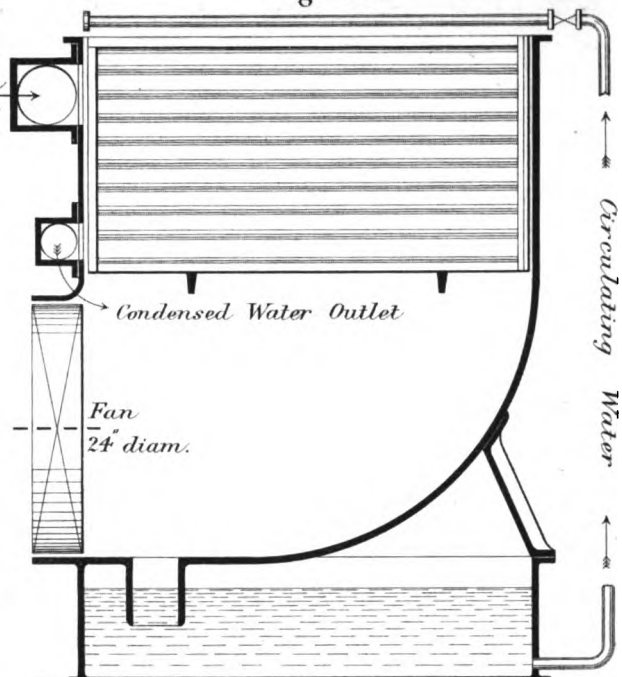
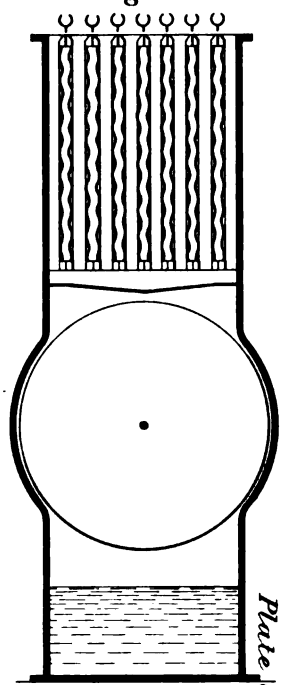


Fig. 95.



Mechanical Engineers **1899.**

Plate 68.

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DIAGRAM OF PROGRESS.

From Commencement.

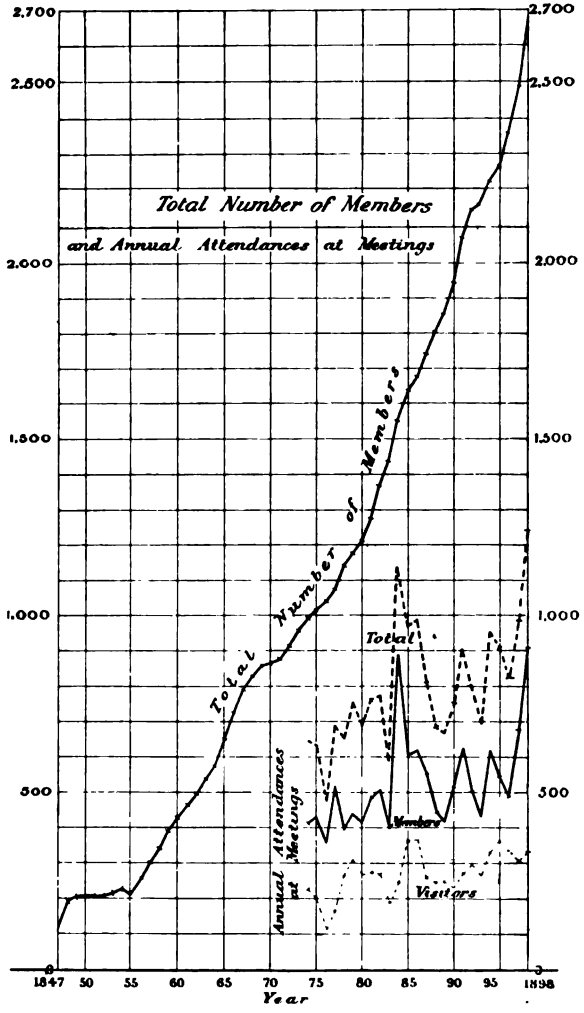

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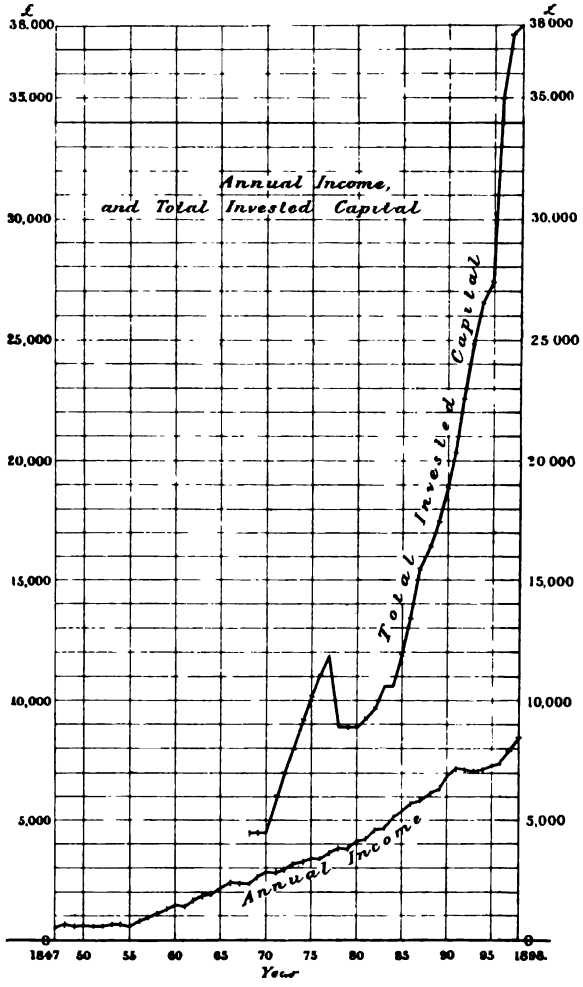
DIAGRAM OF PROGRESS.

From Commencement.



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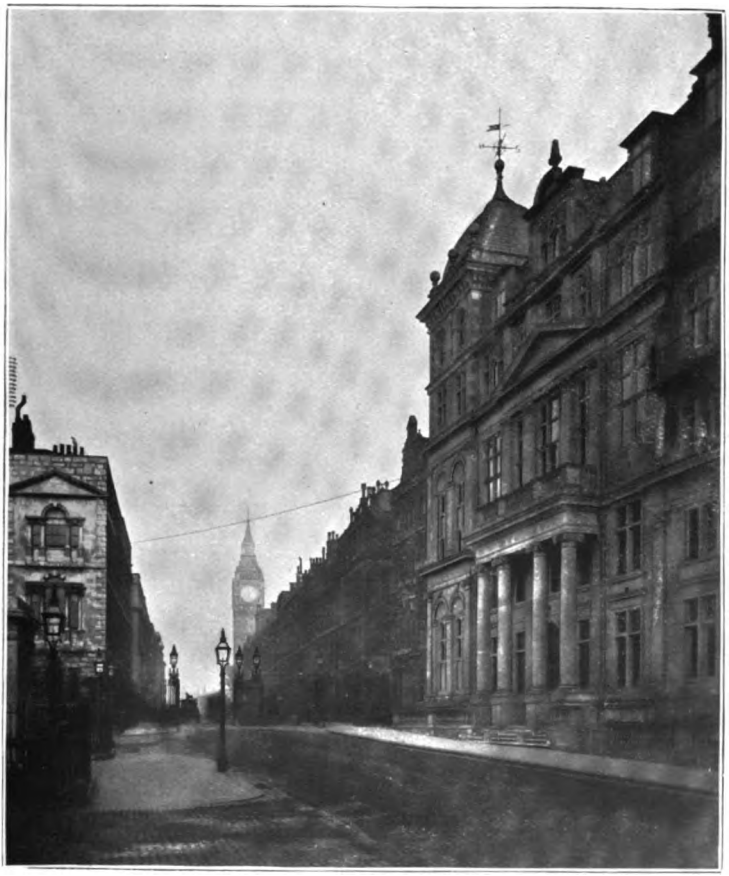

EXTERIOR OF BUILDING.
(Taken from St. James's Park.)

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EXTERIOR OF BUILDING.
(Taken from St. James's Park.)

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ENTRANCE HALL.
(Looking West.)

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TEA ROOM.
(Entresol.)

Digitized by Google

Digitized by Google

TEA ROOM.
(Entresol.)

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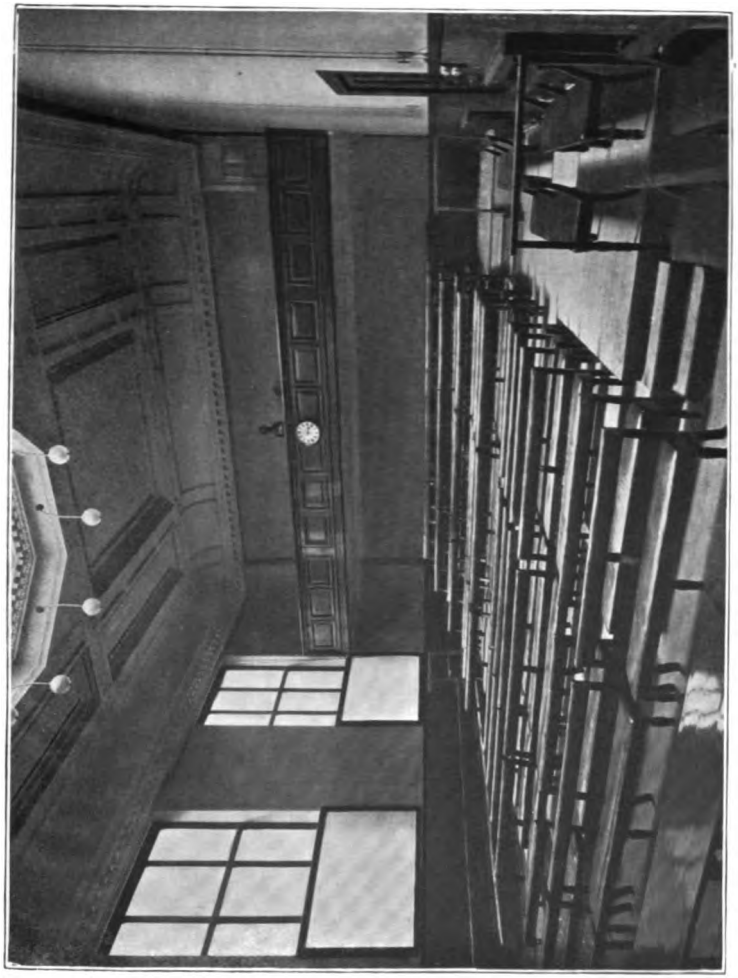

MEETING HALL.
(Ground Floor.)

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COUNCIL ROOM.
(Ground Floor)

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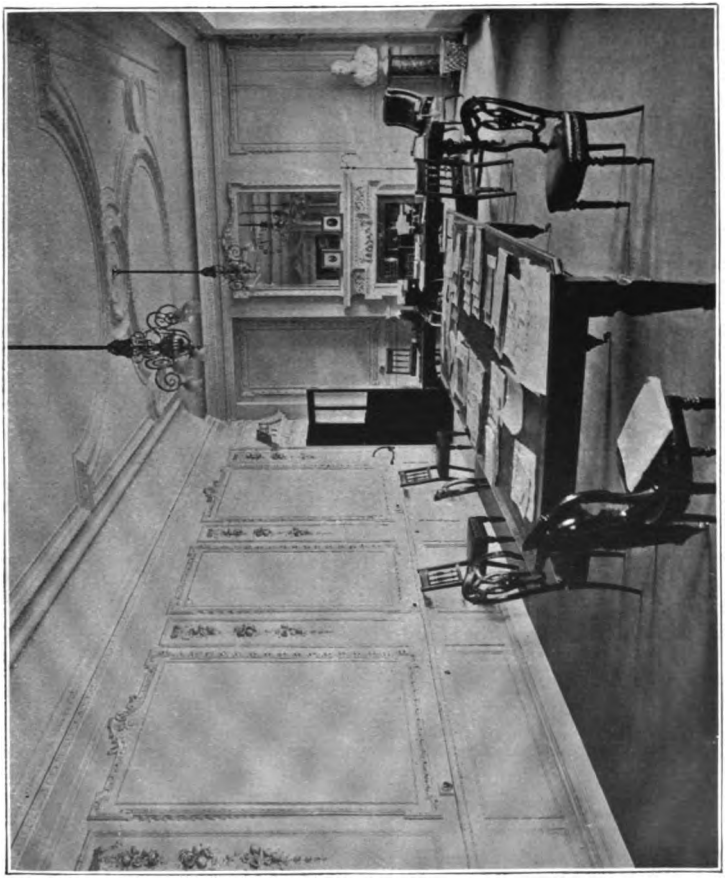

READING ROOM
(Mezzanine)

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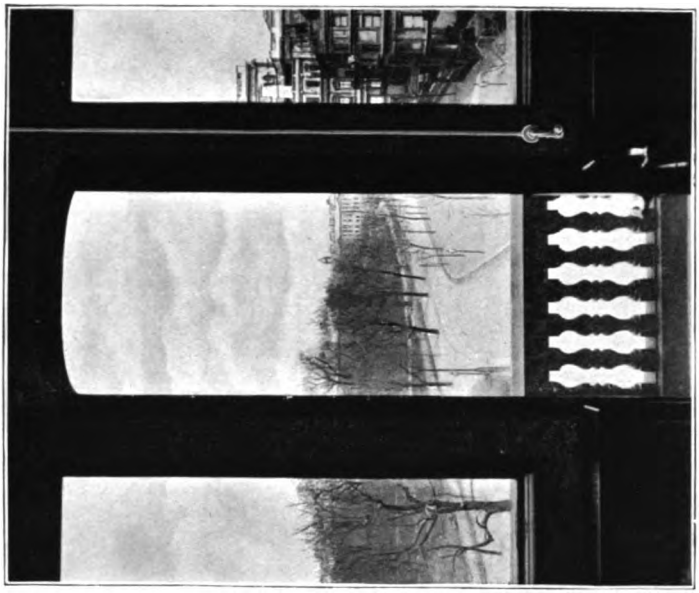
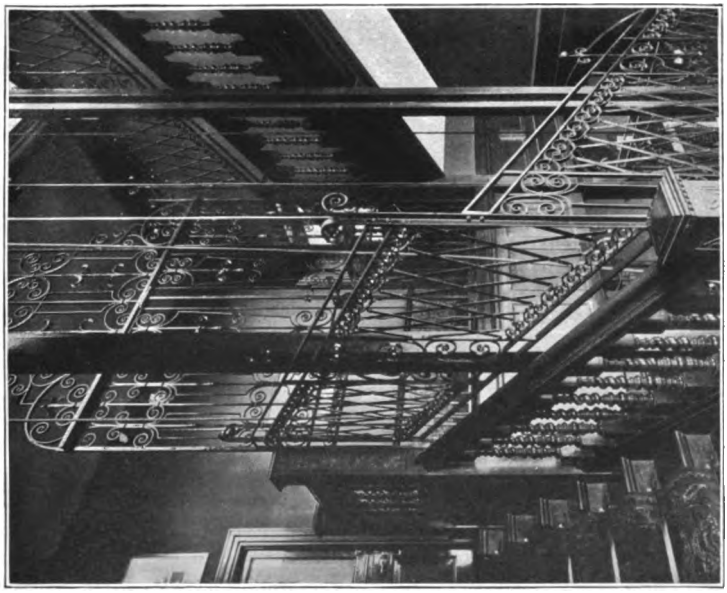


VIEW FROM LIBRARY WINDOW.



STAIRCASE.

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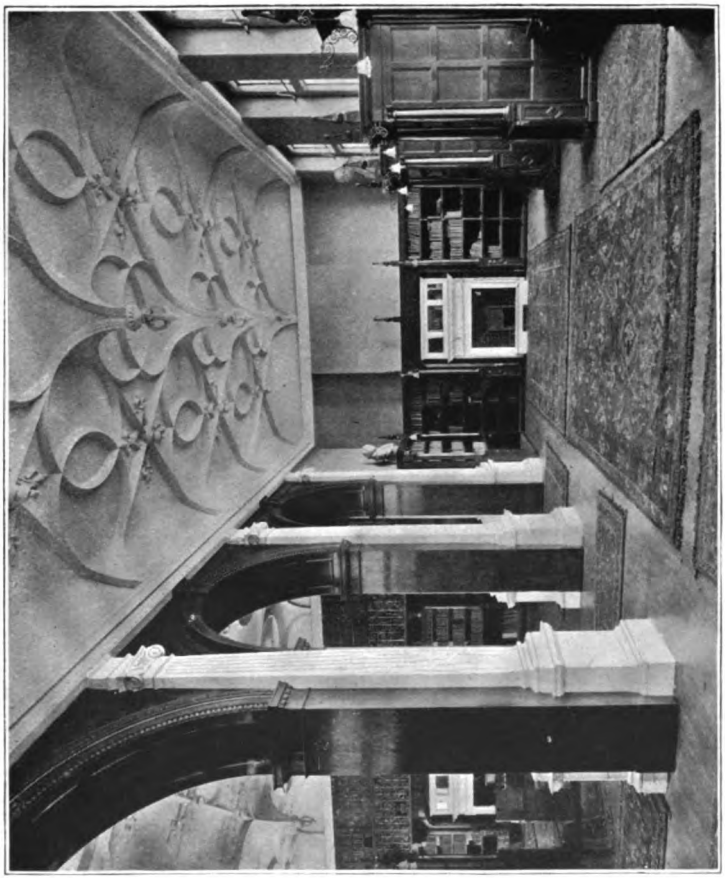

LIBRARY.
(First Floor.)

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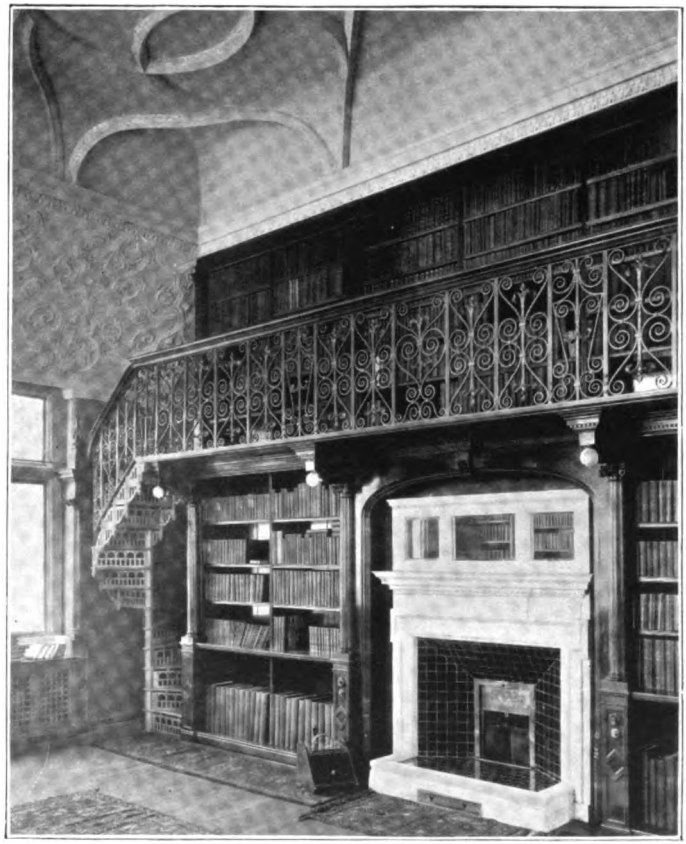

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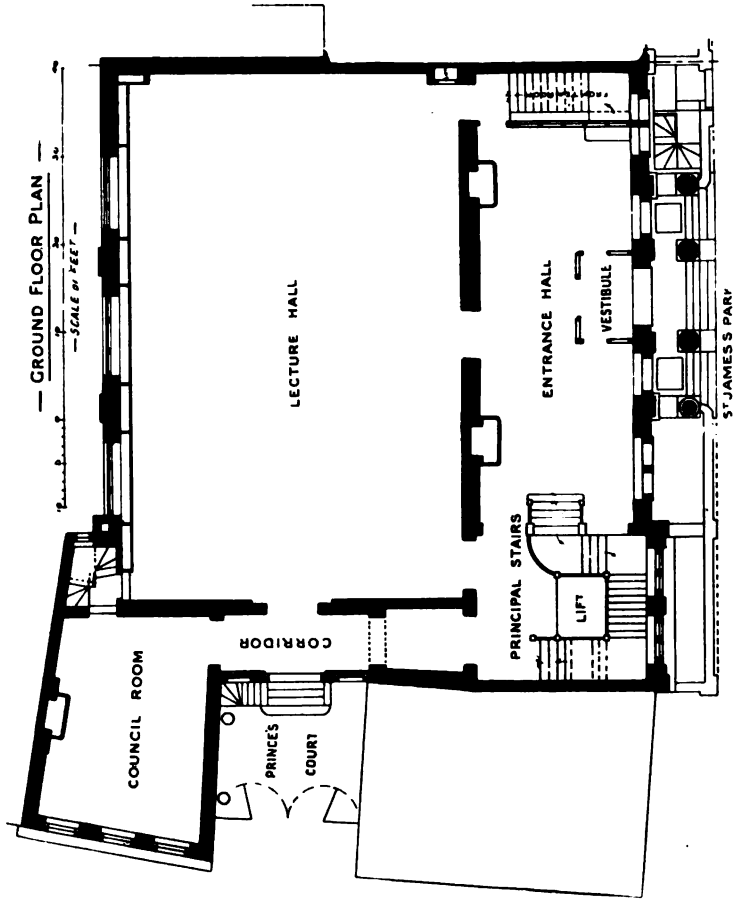

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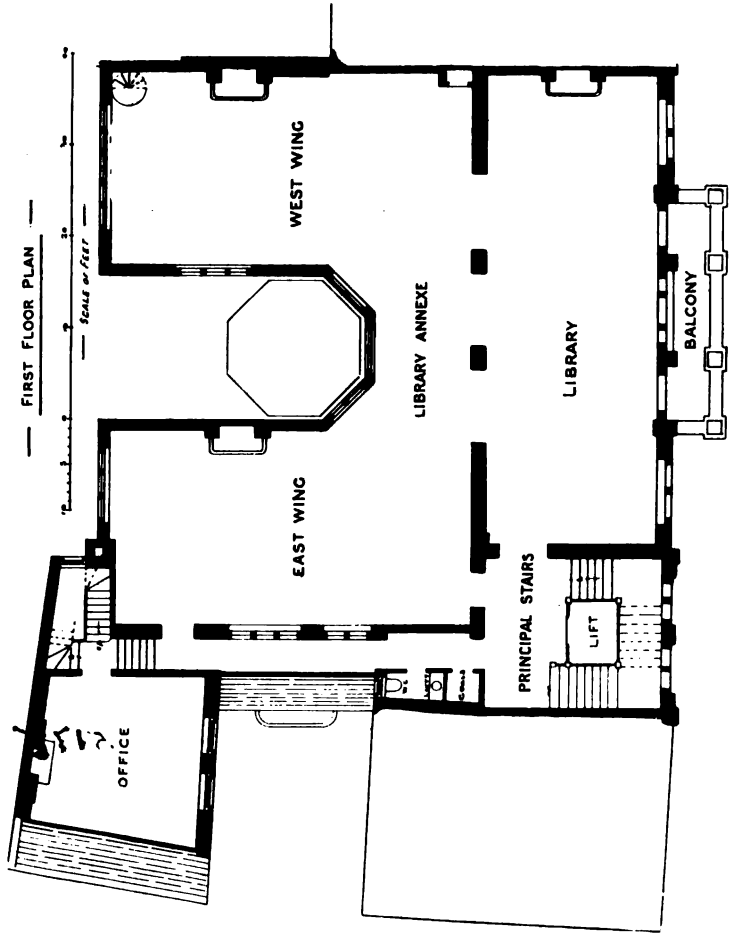

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In compliance with a desire expressed by some of the Members that there should be a convenient arrangement for the uniform binding of the Institution Proceedings, the Council have selected a suitable dark cloth Cover with gilt lettering for the half-yearly volumes; and have arranged that any Member sending his numbers of the Proceedings direct to the binders (not to the Institution) can have them so bound in their half-yearly volumes at the cost of fifteen pence per volume, exclusive of carriage or postage to and fro.

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